The Journal of Bone and Joint Surgery

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The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
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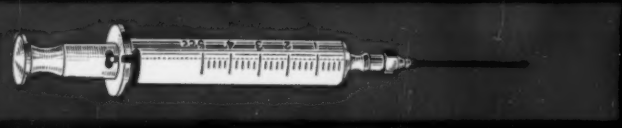

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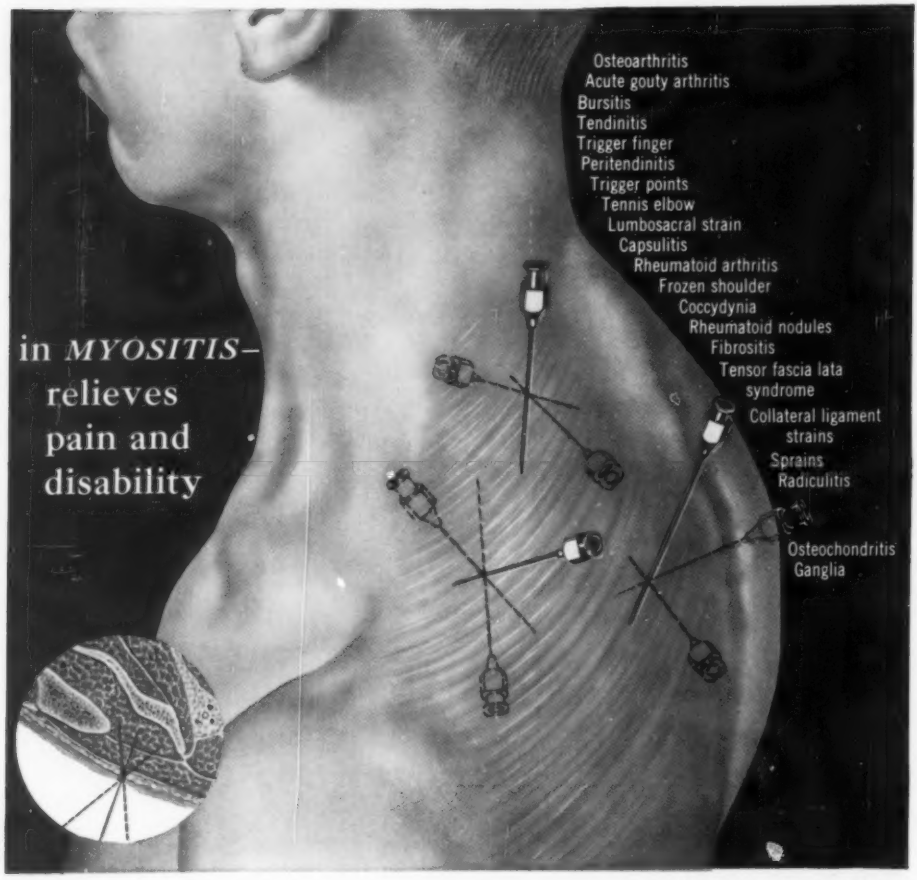

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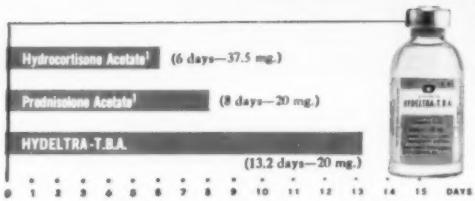
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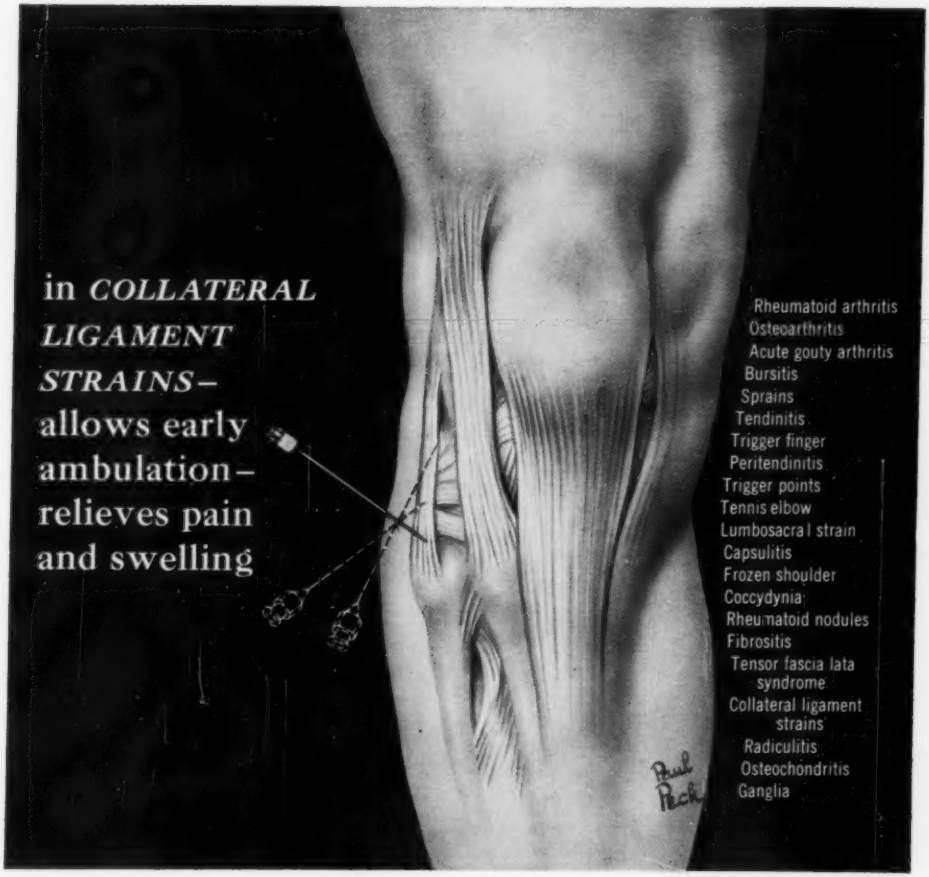

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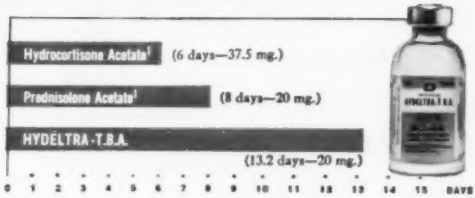
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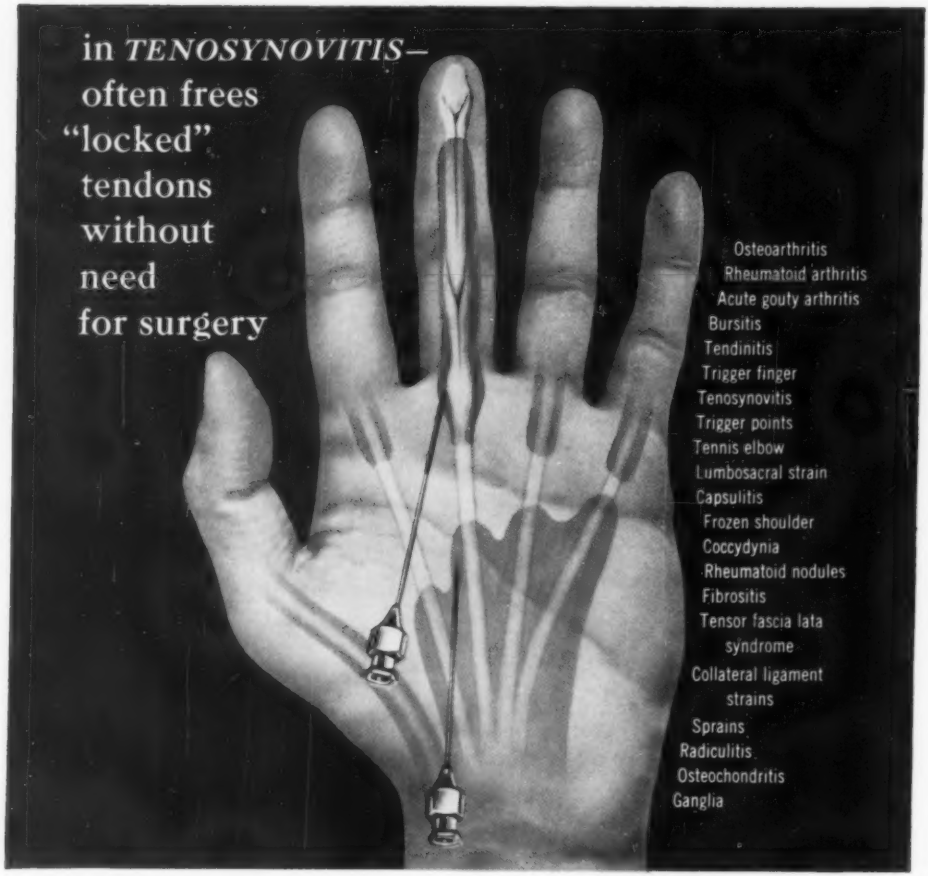

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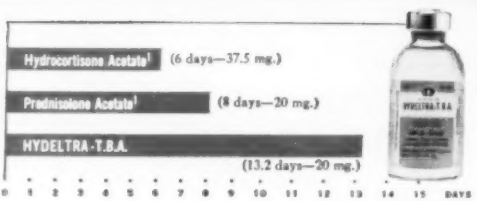
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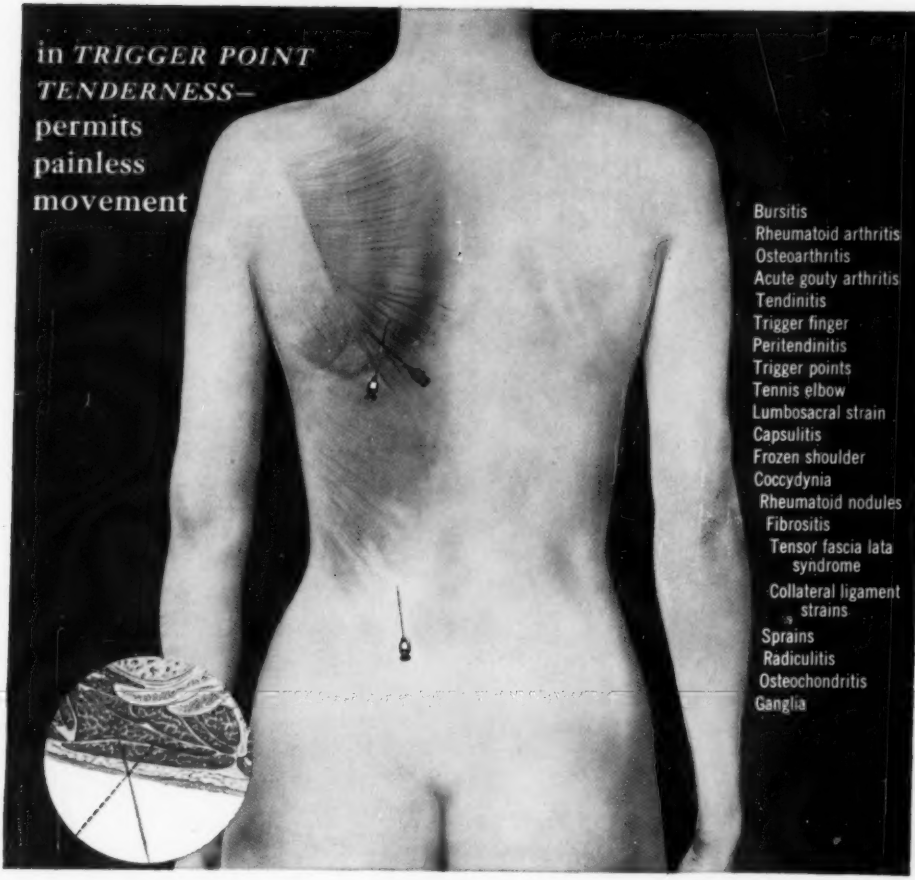

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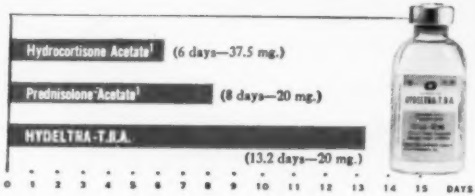
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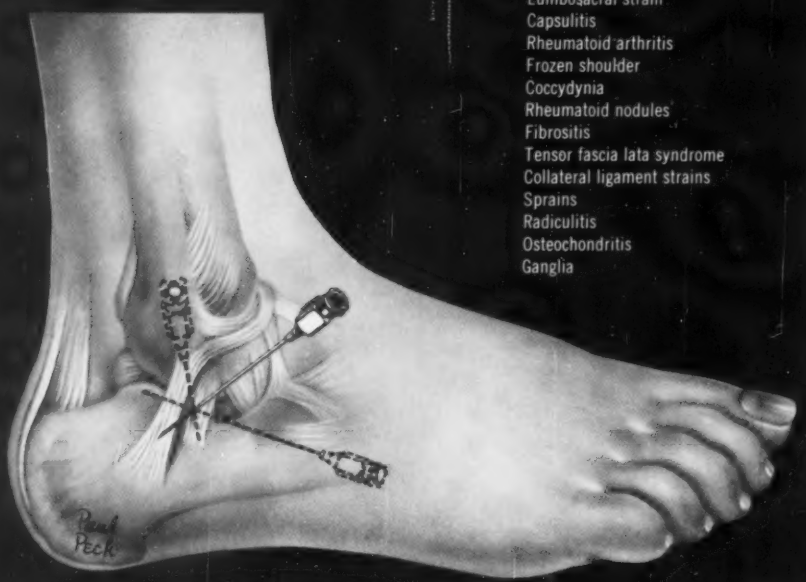

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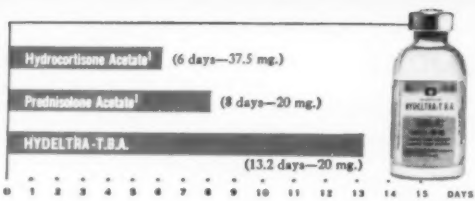
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1. Hollander, J. L., *Paper read at conference in New York City, May 31 and June 1, 1955*

IT'S *New*...IN VITALLIUM

Vitallium®

MODIFIED INTERTROCHANTERIC NAIL-PLATE COMBINATION

(Similar to Thornton Type)

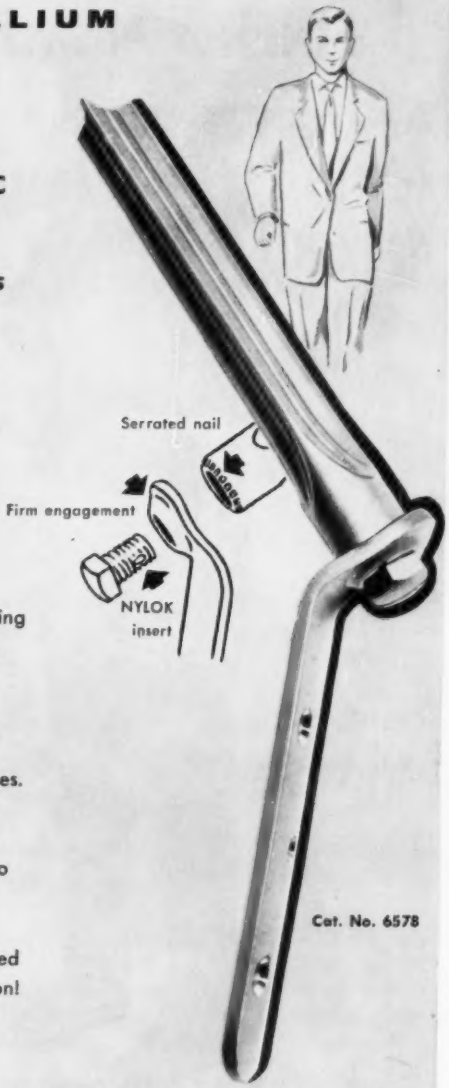
with Many Design Improvements

DIFFERENT • Unlike rigid hip-nailing appliances (McLaughlin and Jewett), this new Vitallium intertrochanteric item may be contoured to suit the case at hand. The plate section is designed to permit contouring to fit anatomical variations of individual femurs, and to compensate for varus or valgus positions.

NEW • Nail and plate are joined by a self-locking bolt and a Nylok* insert, eliminating the difficulty of assembling a two-piece locking screw. Sharp, well-defined serrations on nail and plate assure positive engagement. There can be no slippage.

SIZES • Complete range of plate and nail sizes. Drive shaft and socket wrench also available.

Many requests stimulated the release of this nail-plate combination in Vitallium. There is no electrolytic action between components of any Vitallium multipart appliance. Over 6 million Vitallium surgical appliances have been implanted —without a single authenticated case of corrosion!



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With United States pre-fabricated brace parts, your Orthotist is able to fit your patients better and faster with parts that are interchangeable and easily replaceable. Specify United States pre-fabricated braces to be sure that your patients are equipped with the newest developments in orthopedic appliances.

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Manufacturers of pre-fabricated brace parts, artificial limbs, and surgical supplies.

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"Trilene"®

Brand of trichloroethylene U.S.P. (Blue)

"Duke"® University Inhaler

No. 3160 Model-M

FOR SELF-ADMINISTERED INHALATION ANALGESIA

IN OBSTETRICS

IN MINOR SURGERY

IN PEDIATRICS

■ Notably safe and effective

"Trilene," self administered with the "Duke" University Inhaler, under proper medical supervision, provides highly effective analgesia with a relatively wide margin of safety.

■ Convenient to administer

The "Duke" University Inhaler (Model-M) is specially designed for economy, facility of handling, and ready control of vapor concentration.

■ Special advantages

- Induction of analgesia is usually smooth and rapid with minimum or no loss of consciousness
- Patients treated on an ambulatory basis can usually leave the doctor's office or hospital within 15 to 20 minutes
- Inhalation is automatically interrupted if unconsciousness occurs

"Trilene" *alone* is recommended only for analgesia, not for anesthesia nor for the induction of anesthesia. Epinephrine is contraindicated when "Trilene" is administered.

"Trilene" is available in 300 cc. containers, 15 cc. tubes.

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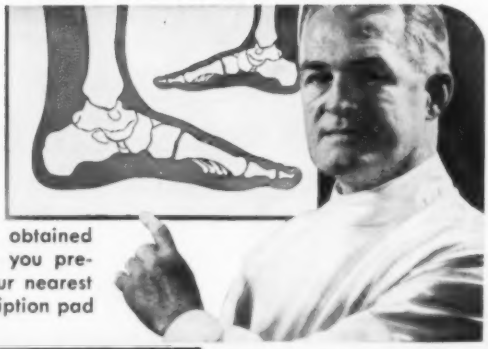

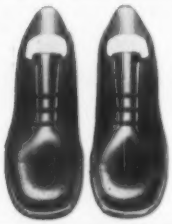

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For Mild Cases
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* NOTE: The perfect shoes for lateral or medial sole wedging.

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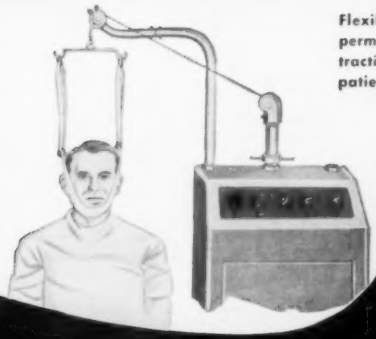


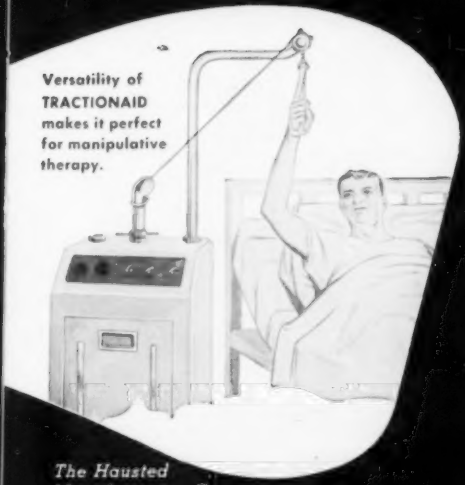
Flexible arms permit cervical traction with patient sitting.

Cervical traction with patient prone. Unit could be behind or at either side of bed.

Whenever traction is indicated...
new, versatile

HAUSTED TRACTIONAID

answers your every need



Versatility of TRACTIONAID makes it perfect for manipulative therapy.

For steady or intermittent traction . . . for cervical, pelvic or manipulative application . . . the new HAUSTED TRACTIONAID is the ultimate in modern therapy.

TRACTIONAID is as advanced beyond old mechanical traction apparatus as the modern jet airplane outstrips Wright brothers first plane.

Electronically controlled and hydraulically operated, TRACTIONAID assures regulated, smooth, positive traction . . . precisely as prescribed. Only TRACTIONAID automatically compensates for patient movement up to 18 inches! And the mobile unit has extension arms to permit traction from any angle, any position, any height. Tension may be regulated from 0 to 100 pounds . . . and on and off intermittent traction timing may be pre-set.

Over three years of severe clinical usage has proved TRACTIONAID not only most effective, but sturdy and trouble-free

Pelvic traction. TRACTIONAID may be moved to any position.

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Complete with head halter and pelvic belt

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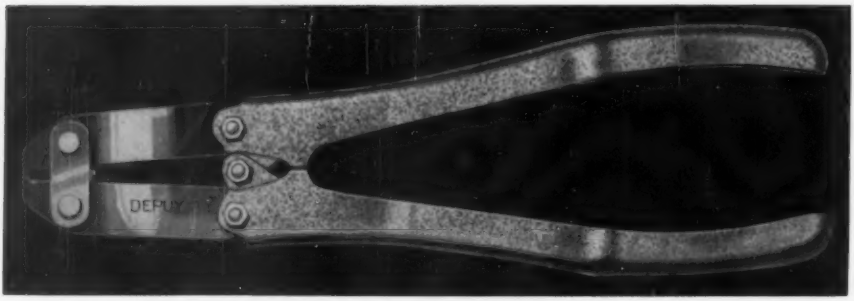
DePuy

UNIVERSAL BONE PLATE

The First Completely Adjustable Intertrochanteric Bone Plate!

The new DePuy Universal Bone Plate is designed to provide both vertical and lateral angulation. In use with conventional Smith-Petersen Nails, cannulated or non-cannulated, or with Lorenzo Screws, it can be regulated quickly and easily during surgery to suit a wide variety of anatomical conditions. Bending of the plate is not required. A range of 35° in the vertical plane of the plate and nail or screw compensates for variance of angle between the femoral head and shaft of the femur. Also, there is a 15° range of lateral adjustment which permits the plate to be moved into flush position after the nail or screw has been impacted. Once angulation is properly adjusted rigid fixation is assured by exclusive concave, serrated locking washer, which is held in place with either the double locking screw combination or a solid Hex bolt. Finest SMO stainless steel. **No. 693.**

DePuy PIN CUTTER



The new DePuy Pin Cutter is designed to meet the need for a powerful end cutter that can cut the pin off flush. This sturdy instrument easily cuts pins up to 3/16" diameter. The jaws are made of especially hardened tool steel to insure long life. The handles, made of plated steel, connect to the jaws through a powerful cam that permits easy operation even when cutting larger size pins. **No. 686.**

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WARSAW, INDIANA

this man needs surgery . . .

But his fears and doubts may seriously complicate your plans.

'Dexamyl' can help you prepare him mentally and emotionally—both for surgery and for an uneventful postoperative course. 'Dexamyl' smoothly and subtly relieves both depression and anxiety. It will help him to view his problems in proper perspective. It will help to restore a normal sense of optimism, cheerfulness and well-being.

Dexamyl* tablets • elixir • Spansule* capsules

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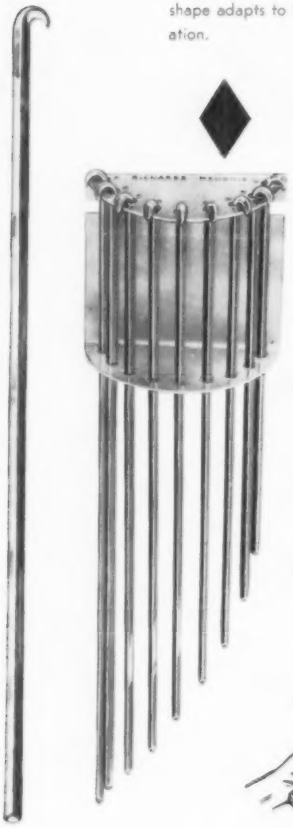
†T.M. Reg. U.S. Pat. Off. for sustained-release capsules, S.K.F.

Richards DIAMOND INTRAMEDULLARY PINS

SMO STAINLESS

Richards diamond intramedullary pins offer the surgeon an aid in the prevention of rotation of fragments.

Flexible in the minor diameter, yet rigid in the major diameter, the diamond cross-sectional shape adapts to the contour of the intramedullary canal, yet provides excellent internal fixation.



PRICE PER SET INCLUDES ALUMINUM RACK

No. 203 Set 7mm x 9mm diameter pins for the FEMUR.

9 pins from 11" to 17" $67.50

Individual pins as follows ..... each 7.50

A	B	C	D	E	F	G	H	I
11"	11¾"	12½"	13¼"	14"	14¾"	15½"	16¼"	17"

No. 204 Set 4mm x 6mm diameter pins for TIBIA, HUMERUS AND LOWER THIRD OF FEMUR.

9 pins from 8" to 14" $54.00

Individual pins as follows ..... each 6.00

A	B	C	D	E	F	G	H	I
8"	8¾"	9½"	10¼"	11"	11¾"	12½"	13¼"	14"

No. 205 Set 3mm x 5mm diameter pins for HUMERUS.

9 pins from 8" to 14" $54.00

Individual pins as follows ..... each 6.00

A	B	C	D	E	F	G	H	I
8"	8¾"	9½"	10¼"	11"	11¾"	12½"	13¼"	14"

No. 206A Set 3mm x 5mm diameter pins for RADIUS AND ULNA.

13 pins from 4" to 10" $52.00

Individual pins as follows ..... each 4.00

A	B	C	D	E	F	G	H	I	J	K	L	M
4"	4½"	5"	5½"	6"	6½"	7"	7½"	8"	8½"	9"	9½"	10"

No. 206B Set 2mm x 3mm diameter pins for RADIUS AND ULNA.

13 pins from 4" to 10" $52.00

Individual pins as follows ..... each 4.00

A	B	C	D	E	F	G	H	I	J	K	L	M
4"	4½"	5"	5½"	6"	6½"	7"	7½"	8"	8½"	9"	9½"	10"

No. 207 Set 2mm x 3mm pins for PHALANGES AND SMALL BONES.

13 pins from 1" to 4" $26.00

Individual pins as follows ..... each 2.00

A	B	C	D	E	F	G	H	I	J	K	L	M
1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"	4"

HAND PIN INSERTER

FOR EITHER ROUND OR DIAMOND PINS

Anodized aluminum to prevent scratching or nicking pins. Thumb screw holds pin in place to gently introduce pin by hand. Not to be used as a driver. One size, 3/16" slot, takes any round pin 3/16" D. or smaller, and both the 2mm x 3mm and 3mm x 5mm diamond pins.

No. 208D $7.50

Richards MANUFACTURING CO., MEMPHIS, TENN.

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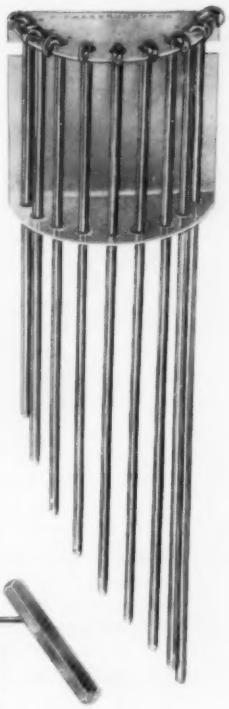
Richards ROUND INTRAMEDULLARY PINS

SMO STAINLESS



Richards round intramedullary pins are carefully formed of selected SMO Stainless of a special temper to give proper resiliency.

Bending irons may be used to pre-shape pin, if desired.

The bullet-nose end of the pin helps to prevent breaking through the cortex, and smoothly guides the pin down the intramedullary canal.

A convenient aluminum rack is furnished at no extra cost with each full set of pins ordered.

No. 261 Set 1/4" diameter pins for femur.

9 pins from 11" to 17" $67.50

Individual pins as follows ..... each 7.50

A	B	C	D	E	F	G	H	I
11"	11¾"	12½"	13¼"	14"	14¾"	15½"	16¼"	17"

No. 262 Set 3/16" diameter pins for Humerus and Tibia

9 pins from 8" to 14" $54.00

Individual pins as follows 6.00

A	B	C	D	E	F	G	H	I
8"	8¾"	9½"	10¼"	11"	11¾"	12½"	13¼"	14"

No. 263 Set 1/8" diameter pins for Radius and Ulna.

13 pins from 4" to 10" $52.00

Individual pins as follows ..... each 4.00

A	B	C	D	E	F	G	H	I	J	K	L	M
4"	4½"	5"	5½"	6"	6½"	7"	7½"	8"	8½"	9"	9½"	10"

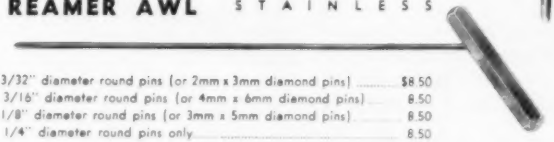
No. 264 Set 3/32" diameter pins for Phalanges, etc.

13 pins from 1" to 4" $26.00

Individual pins as follows ..... each 2.00

A	B	C	D	E	F	G	H	I	J	K	L	M
1"	1¼"	1½"	1¾"	2"	2¼"	2½"	2¾"	3"	3¼"	3½"	3¾"	4"

REAMER AWL STAINLESS



No. 208E—3/32" diameter for 3/32" diameter round pins (or 2mm x 3mm diamond pins) $8.50

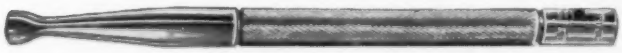
No. 208F—3/16" diameter for 3/16" diameter round pins (or 4mm x 6mm diamond pins) 8.50

No. 208G—1/8" diameter for 1/8" diameter round pins (or 3mm x 5mm diamond pins) 8.50

No. 208H—1/4" diameter, for 1/4" diameter round pins only 8.50

DRIVER EXTRACTOR STAINLESS

FOR EITHER ROUND OR DIAMOND PINS



No. 208A—3/32" round or 2mm x 3mm diamond $7.50

No. 208B—1/8" round or 3mm x 5mm diamond 7.50

No. 208C—3/16" round or 4mm x 6mm diamond 7.50

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STYLE NO. 63

Alden-Pedic lasts are designed to accommodate your prescribed corrections and insertions. Extreme sizes stocked. Many styles available for men, boys. Top quality only.

Alden-Pedic lasts and shoes have been scientifically designed and tested to accommodate specific and general degrees of foot disabilities. To fit the foot shape and accommodate the prescribed corrections is the crux of our program. Doctors who become familiar with the functional merit of this program will be glad to prescribe these shoes as a foundation in the treatment and correction of foot disabilities. We do not claim that these shoes will correct abnormal foot conditions, but they will provide the types of basic footwear necessary as a foundation in aiding foot trouble and in offering foot comfort. We know you will be glad to recommend them.

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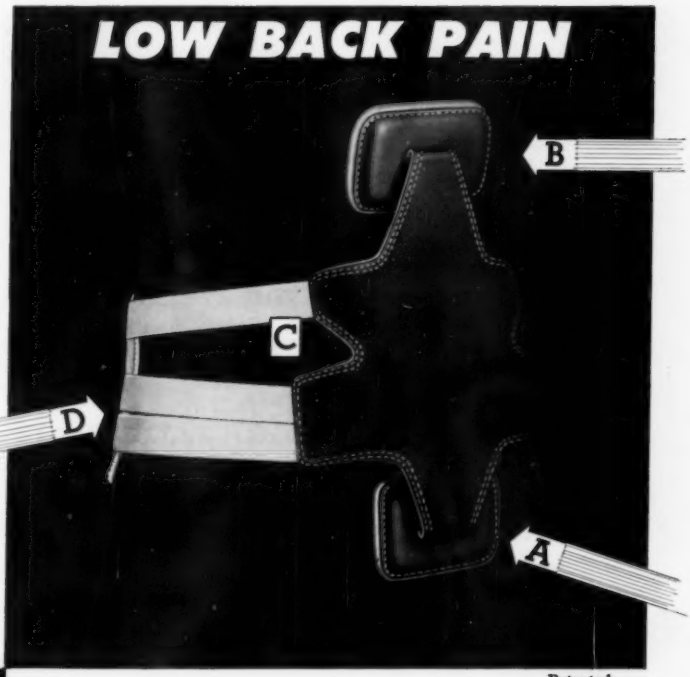
Custom Bootmakers Since 1884

LOW BACK PAIN

Announcing a New Principle of Relief with the Bell Posture Bridge by TRUFORM



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Eases facet impingement in the lumbo-sacral area by means of entirely unique 3-point pressure. Observe in the photo these key features:

Exerts Positive Forward Thrust to tilt the pelvis, by direct contact of the lower pressure pad with the posterior surface of the sacrum. A

Corrects Posture Defect, even excessive lordotic lumbar curvature . . . with the upper pressure pad acting as a fulcrum. B

C *Makes No Other Contact* along the back, between the Bridge's two "piers" . . . there is no interference with the positive pressure of the two pads.

D *Applies Controlled Counter-Pressure* by means of the tightly-pulled straps.

"*Seeing Is Believing*" . . . so welcome the Truform fitter in your city, Doctor, when he calls to show you this new Bell Posture Bridge. Only by actually examining and applying this unique support can you fully appreciate its perfect adaptability to the relief of low back pain. Over 500 patients . . . with and without sciatic involvement . . . have already proven the Bell Posture Bridge during its development and clinical evaluation.

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Zimmer Instruments and Appliances for Orthopedic Surgery

MYO-CERVICAL COLLAR

The Myo-Cervical Collar is used for whip lash injuries, arthritic necks, torticollis or wry neck, and generally to stabilize or slightly hyperextend the cervical region. It has also been used in place of sand bags in the operating room to stabilize the head in cataract operations, and for head stabilization after facial plastic surgery. (It has been used as a follow-up to the cast or Forrester Collar in cases of cervical fractures.)

FRONT VIEW

Adjustable in height. Soft plastic covered sponge rubber contact parts add patient comfort. Light in weight and well ventilated.

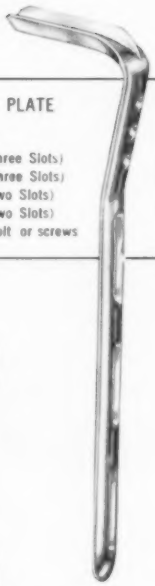
BACK VIEW

Snap fastener. Adjustable neck size. White polyethylene plastic — easily cleaned.

ELLIOTT FEMORAL CONDYLE BLADE PLATE

Designed by Dr. Robert B. Elliott, Houston, Texas

No. 554A 2¼" inside blade length x 8" plate (Three Slots)
No. 554B 2¼" inside blade length x 8" plate (Three Slots)
No. 554C 2¼" inside blade length x 6" plate (Two Slots)
No. 554D 2¼" inside blade length x 6" plate (Two Slots)
Holes are for a tibia bolt or screws

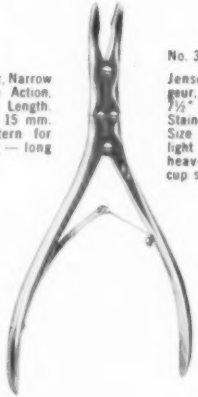


No. 3812

Brun Plaster Shear, 9½", Stainless Steel. Heavy duty plaster shear.

No. 3325

Beyer Rongeur, Narrow Jaw, Multiple Action, 7½", Overall Length. Cup size 4 x 15 mm. Delicate pattern for fine cutting — long narrow jaw.



No. 3322

Jensen-Zaufel Rongeur, Multiple Action, 7½" Overall Length, Stainless Steel. Cup Size 5 x 14 mm. For light work — slightly heavier than 3325 — cup shaped jaw.

Zimmer

Look for the trademark ⟨Z⟩

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In Canada Available through selected surgical supply dealers or through our Agents, Fisher & Burpe, Ltd.

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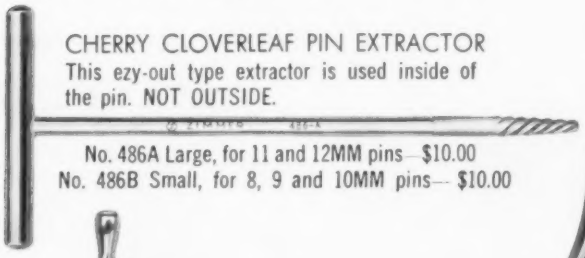
No. 825
Schneider self broaching pin $11.50 each

SCHNEIDER **SELF BROACHING** INTRAMEDULLARY PIN . . . . .

- No need for special instruments.
- Prevents rotation of fragments.
- Maximum strength for weight of pin.
- Cuts its own way—less chance of splitting the shaft.
- Larger sized nail can be used for a snug fit.
- May be driven or extracted from either end.
- Less chance of getting out of the groove.
- Grooves allow for free outflow of marrow fat.
- SIZES: 8mm. to 12mm. diameters.



CHERRY CLOVERLEAF PIN EXTRACTOR
This ezy-out type extractor is used inside of the pin. NOT OUTSIDE.

No. 486A Large, for 11 and 12MM pins—$10.00
No. 486B Small, for 8, 9 and 10MM pins—$10.00

"Small Hand Drill"
No. 895
Price $45.00

Lamina Spreader
No. 661
Price $65.00

Zimmer

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In Canada Available through selected surgical supply dealers or through our Agents, Fisher & Burpe, Ltd.

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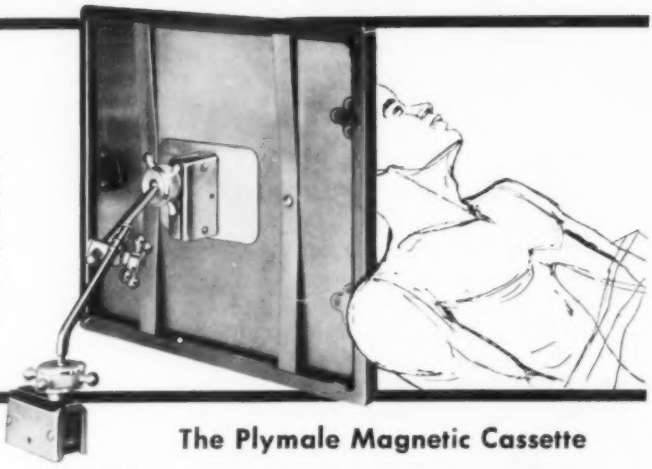
The New PLYMALE MAGNETIC* CASSETTE HOLDER for lateral and oblique x-rays

. . . enables clear pictures easily, safely

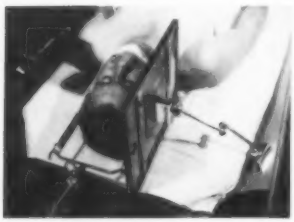
NOW! Eliminate irradiation hazard!

No cassette "hand holding" to steady cassette during long exposure. No danger of irradiation resulting in lost fingers and hands. Using the Magnetic Cassette Holder during the x-ray, your technician can leave the zone where irradiation danger exists.



* **125 lb. magnetic pull**
Two powerful magnetic bases provide dependable grip on cassette. The magnetic cassette holder quickly adjusts and locks to instantly hold cassette secure at any position. Each cassette holder is provided with steel plates which attach to the back of any aluminum or magnesium cassette.

The Plymale Magnetic Cassette Holder's versatility gives proper alignment for consistently clear exposures



EMERGENCIES
The Plymale Magnetic Cassette Holder helps portable x-ray units take easy-to-interpret pictures in emergency room, hospital bed, clinic or on the stretcher. It quickly sets the cassette in place allowing technicians to process emergencies without movement from stretcher or assistance from another technician.

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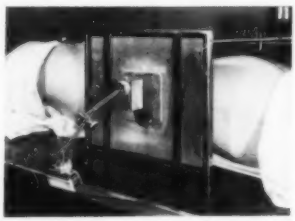

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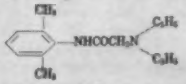
Chemical Name: α-Diethylaminoaceto-2,6-xylidide

Chemical Structure:



Potency: Two to three times that of procaine.

Duration of Action: Two to three times that of procaine.

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Safety Factor: Two to three times that of procaine (because smaller concentrations and volumes are clinically as effective).

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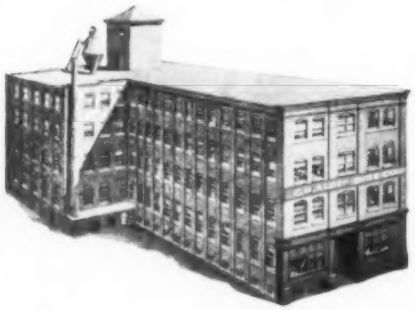

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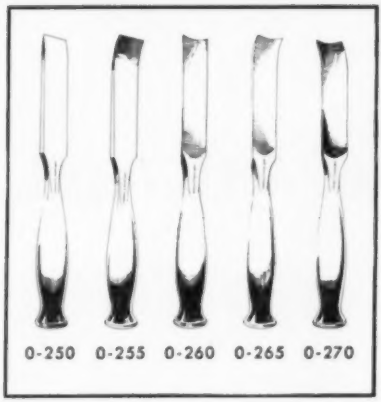

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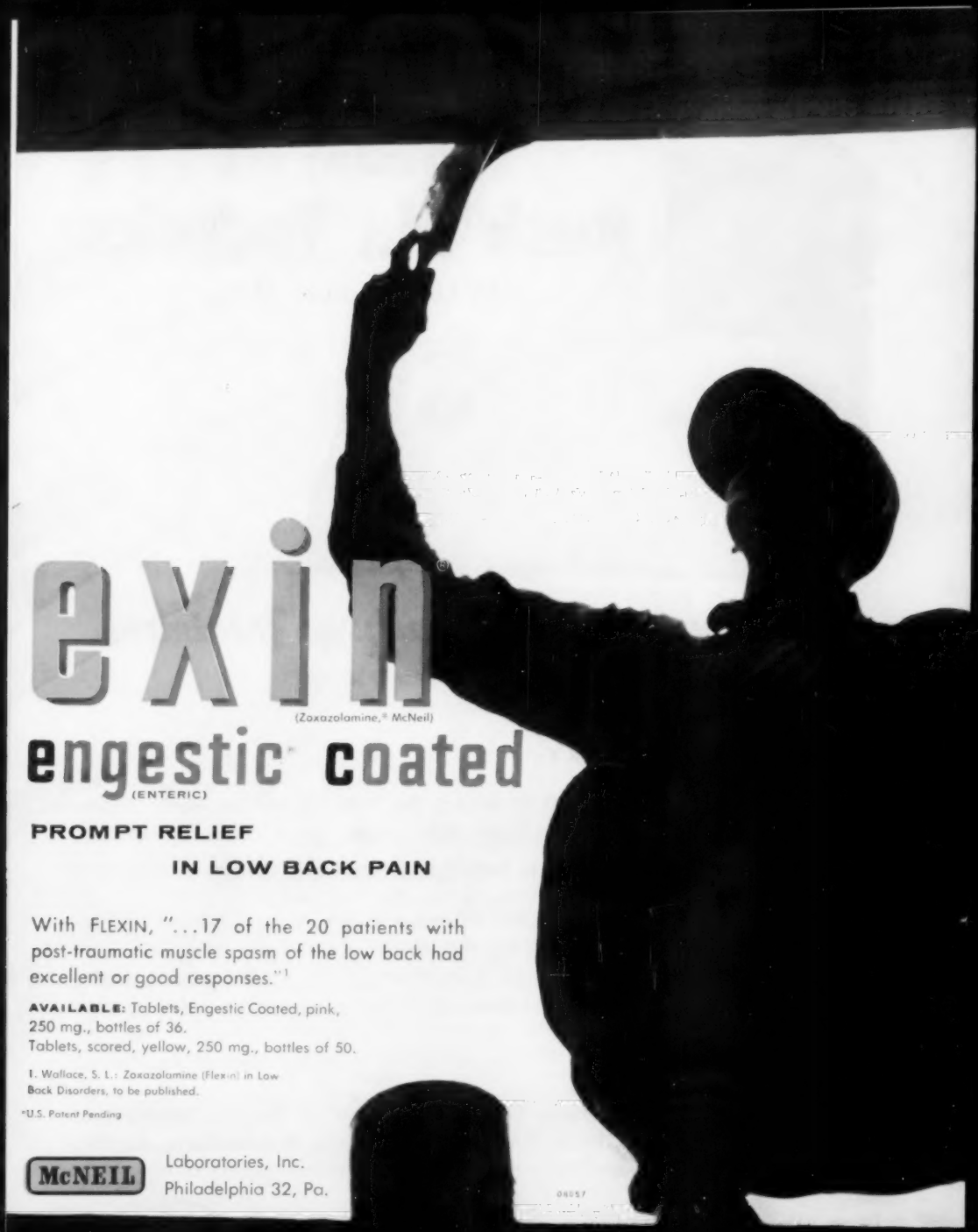
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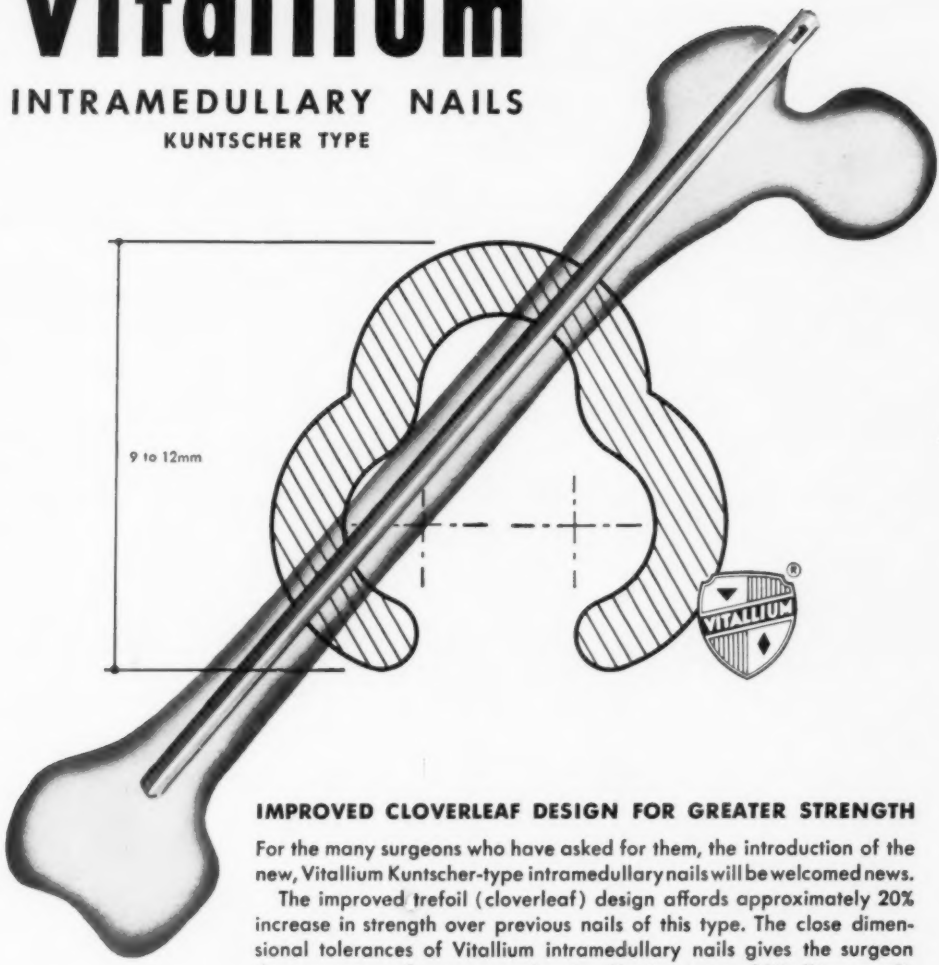

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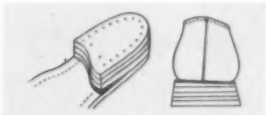

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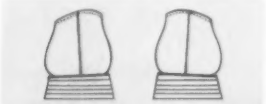

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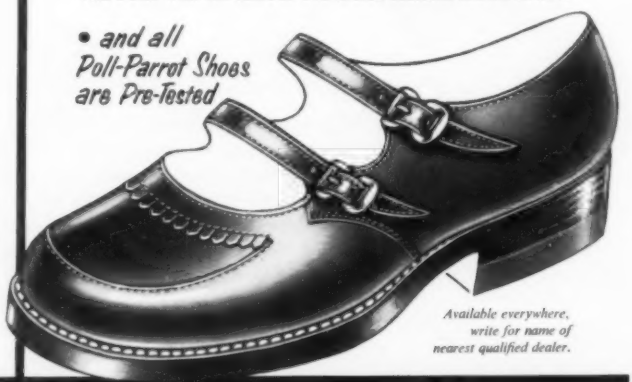

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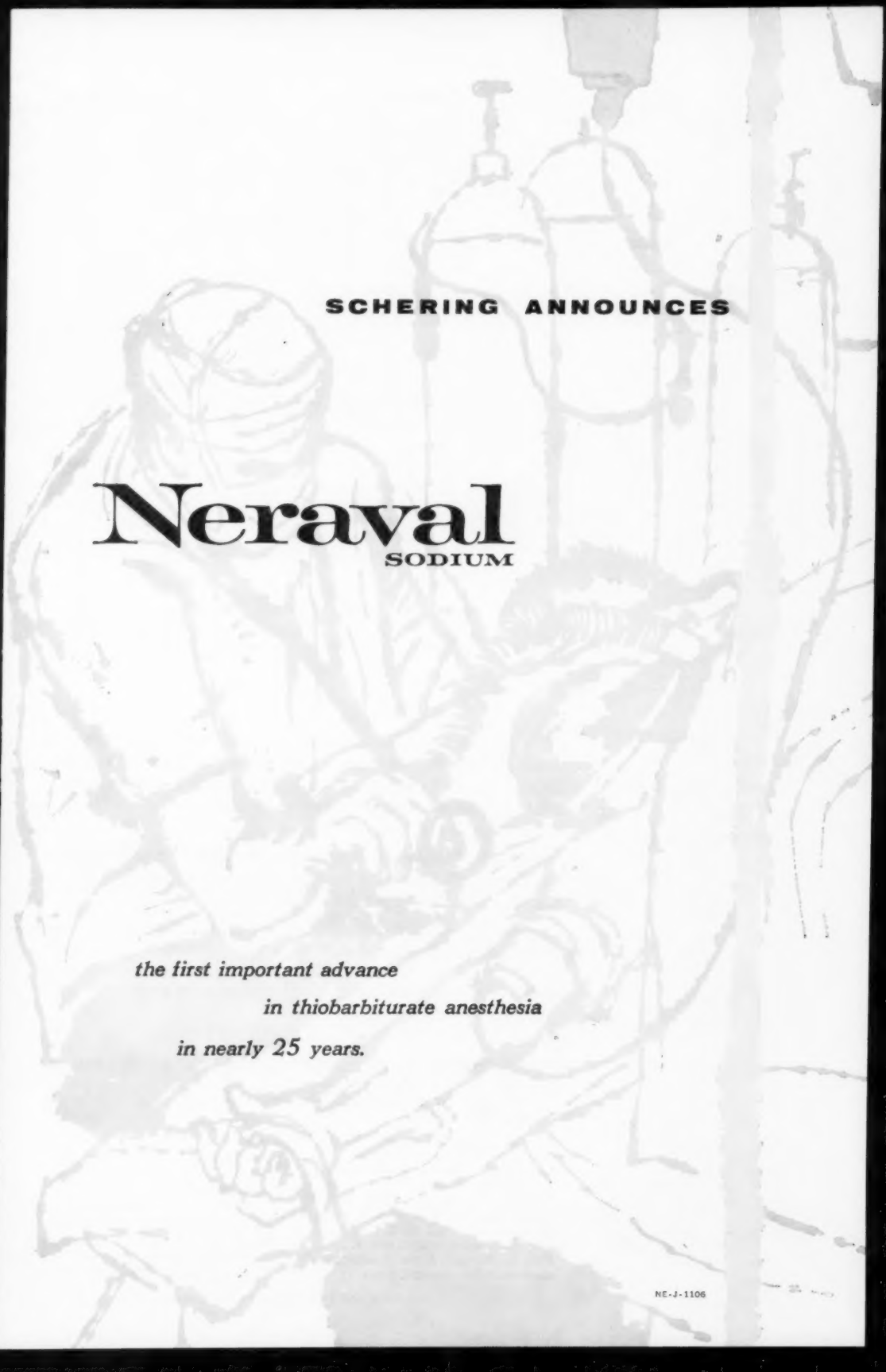

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1. Boone, J.D.; Munoz, R., and Dillon, J.B.: Anesthesiology *17*:284, 1956. 2. Zima, O.; von Werder, F., and Hotovy, R.: Anaesthesist *5*:244, 1954. 3. Fitzpatrick, L.J.; Clarie, D'A., and Mersch, M.A.; To be published. 4. Blake, M.W. and Perlman, P.L.: J. Pharmacol. & Exper. Therap. *117*:287, 1956. 5. Ayd, F.J., Jr.: Neraval: A new anesthetic for electroconvulsive therapy, paper presented at annual meeting, Electroshock Research Association, Chicago, Illinois, April 29th, 1956. 6. Irwin S.; Stagg, R.D.; Dunbar, E., and Govier, W.M.: J. Pharmacol. & Exper. Therap. *116*:317, 1956. 7. Reifferscheid, M., and Dietmann, K.: Deutsche med. Wchnschr. *79*:638, 1954. 8. Dietmann, K.: Deutsche med. Wchnschr. *79*:1748, 1954.

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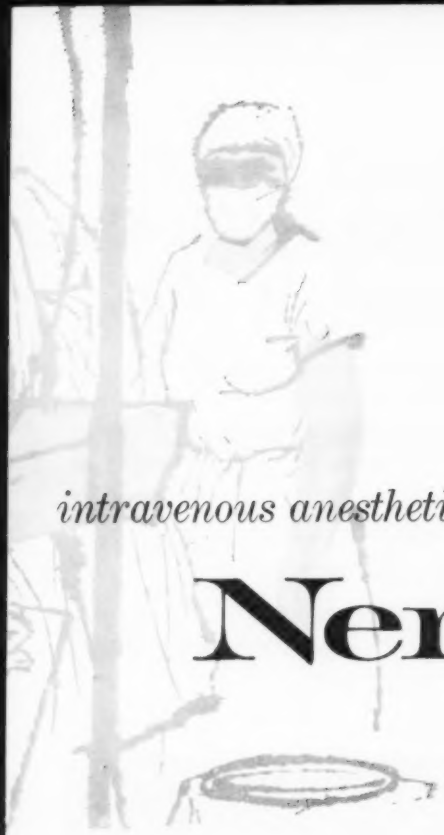

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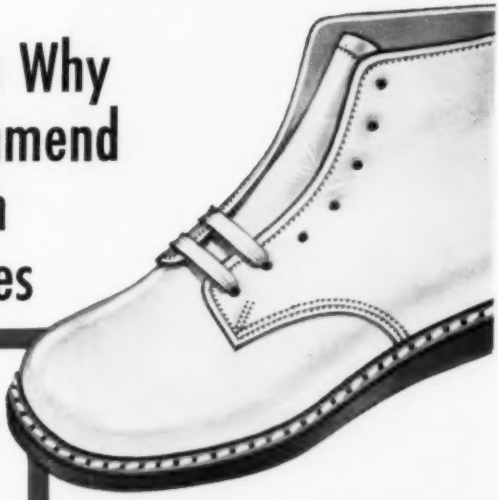

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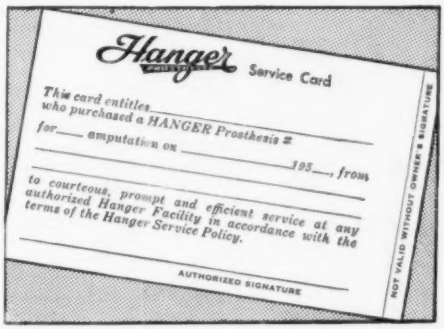
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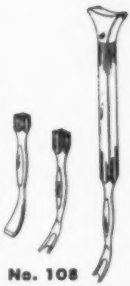

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A Clinical Evaluation of Tendon Transplantation in the Paralytic Foot *

BY LEE RAMSAY STRAUB, M.D., J. PAUL HARVEY, JR., M.D., AND CHARLES E. FUERST, M.D., NEW YORK, N. Y.

From the Hospital for Special Surgery, New York

Tendon transfer in the paralytic or deformed foot has enjoyed cyclic popularity since the first recorded operation by Nicoladoni in 1881[2,7]. The excellent early studies of Lange and Mayer and many others laid a firm foundation for tendon surgery. The principles set forth have not appreciably changed[2,5]. Yet there still remains divergence in opinion as to the usefulness of these procedures. Transfers appear to have been popular in one decade, criticized in the next.

The authors have conducted a follow-up study on all of the tendon transfers in feet done at the Hospital for Special Surgery from 1935 to the present. Of 332 patients invited, 164 came in for personal follow-up examination by one or more of us. One hundred and eighty-one feet are included in this series.

This is a clinical review, and as such, has definite limitations. Of the patients followed, 133 suffered from the residua of poliomyelitis with distinct variation in deformity and involvement. The original muscle-grading was done by many workers, as was the surgery, and the operative techniques varied widely. Statistics here recorded must be viewed with these facts in mind.

We have learned in this study that there is no simple formula that can express the widely divergent problems of the paralytic or deformed foot and the surgical solution for each.

Method of Study

In order to avoid the confusion of a large number of subclassifications of deformity, the patients have been separated into broad groups:

1. Patients who have had transplantation of the extensor hallucis longus with or without interphalangeal fusion (the Jones operation) and its variations form the largest group. The deformity in these patients follows a general pattern of hyperextension and cock-up of the great toe, dropping of the first metatarsal head, cavovalgus, and frequently equinus. The usual important deforming factor is paralysis of the tibialis anterior.

2. The next large group consists of valgus deformities resulting from poliomyelitis. No effort is here made to separate equinovalgus or calcaneovalgus, as the corrective operations have been largely transfer of one or both peroneal tendons to the dorsum of the foot.

* Read at the Annual Meeting of The American Orthopaedic Association, White Sulphur Springs, West Virginia, June 20, 1955.

TABLE I

GRADE OF MUSCLE LOSS AFTER TENDON TRANSFER

Tendon Transferred	Grade of Muscle Loss	No. of Cases
Tibialis anterior	1.6	16
Tibialis posterior	2.1	6
Peronaeus longus	2.0	59
Peronaeus brevis	1.7	32
Extensor hallucis longus	1.0	82
Extensor digitorum longus	0	4

TABLE II

RESULTS IN SEVENTY-FOUR CASES WITH TENDON TRANSFER AND TRIPLE ARTHRODESIS

	Rating Scale				
	4	3	2	1	0
Tendon rating (No. of cases)	20	13	8	13	20
Over-all rating (No. of cases)	31	32	9	1	1

3. The same is true of the next group, varus deformity resulting from poliomyelitis, since here also the similarity of the operations performed sets the pattern. In most cases, the tibialis anterior tendon was transferred laterally.

4. Calcaneus deformities following poliomyelitis were treated by tendon transfers to the heel. These, therefore, form another group.

The following groups of patients have been separated by diagnosis:

5. Congenital club-foot.

6. A few miscellaneous conditions for which tendon transfer has been done.

7. Cerebral palsy.

There has been no selection in this series of patients. All patients who reported in person at our invitation have been included.

Rating of End Results

The end result of transferred tendon function was rated on a 4 to 0 scale. Muscle strength in the transplant equal to that of the preoperative level is represented by 4. Muscle-grading below this level has been on the usual five-point basis. Classification of triceps surae power is less well defined. A fair tendo achillis cannot be "broken" by the examiner, but does not quite provide strength for unaided elevation of the body weight. It does not have sufficient strength to eliminate a calcaneus type of gait.

The over-all result of all surgical procedures to a foot was also rated on a 4 to 0 basis. A 4 rating represents the achievement of the surgeon's preoperative aims. Often a tendon rating was 0 but the over-all rating was 4 because of satisfactory operative stabilization of the foot, or because of the removal of a deforming factor by the tendon transfer even though the tendon was not functioning in its new position.

FINDINGS OF GENERAL INTEREST

A total of 214 tendons were transferred singly or in combination in 181 feet.

Muscle Strength after Transfer

Excluding transfers to the heel cord, because of our inability to rate these muscles separately, the average drop in rated strength for the entire group was 1.5 grades per

TABLE III

	Total No. of Cases	Triple Arthrodesis (*No. of Cases*)
Extensor hallucis longus transfer	75	18
Valgus deformity	40	32
Varus deformity	11	5
Calcaneus	12	5*
Club-foot	25	4
Miscellaneous	12	7
Cerebral palsy	6	3

* Triple arthrodesis is anticipated in five additional cases.

muscle for 199 muscles transferred in patients with poliomyelitis. The average loss for specific muscles used singly or in combination is given in Table I. The loss for the tibialis anterior in club-foot was 0.6 grade.

In rare instances an increase in strength by one grade was recorded. This was due to errors in muscle rating, in our opinion.

Relation of Osseous Stabilization to Outcome of Tendon Transplantation

In the entire group of feet triple arthrodesis has been performed seventy-four times. The postoperative rating for tendon transfer in these cases is shown in Table II.

Triple arthrodesis after tendon transplantation was done in eight feet. Five of these received an over-all rating of 4; three were rated 3. In eight feet the triple arthrodesis preceded the transplantation; three were rated 4; three at 3; and two at 2. Tendon transfers were done simultaneously with stabilization in fifty-eight feet. The over-all rating was 4 in twenty-five, 3 in twenty-five, 2 in six, 1 in one, and 0 in one, making a total of fifty satisfactory results. Table III lists the number of triple arthrodeses performed in relation to the various groups.

For the most part triple arthrodesis has been reserved for the more seriously involved feet with muscle imbalance and persistent instability. Appropriate bony stabilization appears to be particularly important in the treatment of calcaneus and valgus deformities.

Method of Tendon Insertion

Tendons have been inserted by three different methods: (1) By intra-osseous suture or the implantation of the tendon into a bed or channel of bone with suture of the tendon to bone and to periosteum. (2) By the loop method, that is, passage of the tendon end through an osseous tunnel and back to be sutured to itself. (3) By Bunnell's method using a pull-out wire passed through a hole in the bone of insertion, the wire being tied over a button on the sole of the foot. In some instances a chromic catgut suture was employed instead of wire and the pull-out feature was eliminated. This latter method is less certain of secure hold.

We find little, if any, difference in the total results in the three groups listed above. Good results—those rated 4—were obtained in 37 per cent of the fifty-nine feet with intra-osseous sutures; in 33 per cent of 106 feet with loop sutures; and in 52 per cent of forty-four feet with Bunnell sutures.

Tension of Tendon Transfers

The tension under which a tendon is attached to its new site is seldom recorded in operative notes. When it is recorded, the exact degree is a matter of personal definition. We can, therefore, give only a clinical impression in this regard. In our opinion, one of the chief causes of failure in tendon transfer is inadequate tension. There have been no

instances of persistent deformity due to excessive tension in the transfers. We recommend, then, that tendons be attached under strong tension.

Deformity in Relation to Tendon Transfers

Our findings confirm the statements of Mayer and Peabody that tendon transplantation will not correct a fixed deformity. This is especially noticed in transfers of tendons to the dorsum of the foot designed to provide dorsiflexor balance. These transfers will not give real benefit in the presence of a contracted heel cord. A transferred tendon rarely may produce a deformity. This may occur directly as the result of the function of the tendon in its new position or indirectly as the result of the loss of the function of the tendon

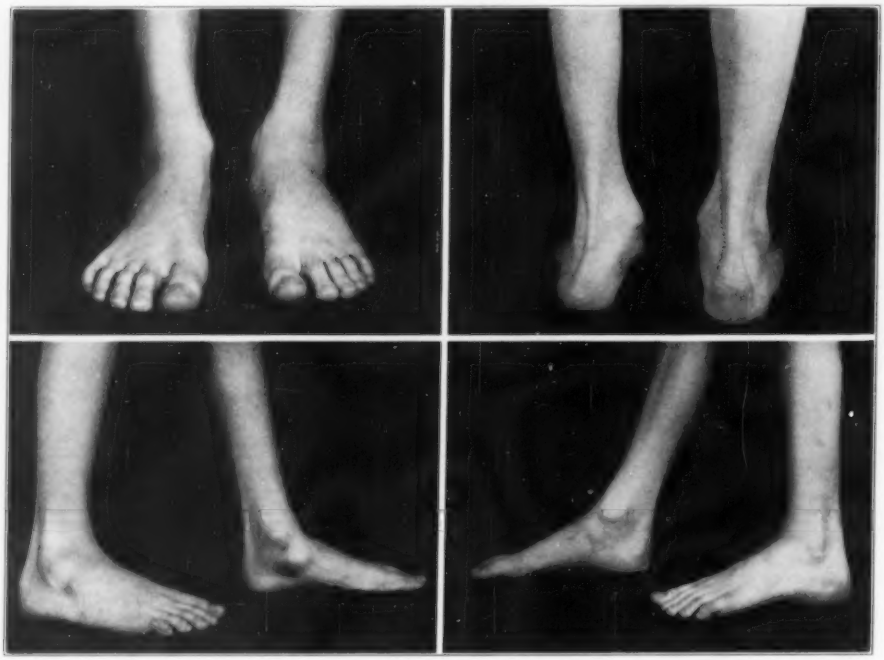

FIG. 1-A

A. P., male. Preoperative photographs made in August 1948, showing valgus deformity of left foot.

in its original normal position. An example of the first situation was noted in a patient in whom transfer of the peronaeus longus to the region of the tibialis anterior produced a varus deformity. An example of the second situation was seen in a patient in whom transfer of the tibialis anterior laterally resulted in a hyperextension deformity or cock-up of the great toe. This required a later Jones operation. It is interesting to note that while the tibialis anterior was regularly shifted laterally in the patients with club-foot, none of these has required later Jones operation. A slight cock-up tendency of the great toe has frequently appeared but has not caused complaint.

Age at Time of Transfer

In most of the patients in this series tendon transfers were done in the first and second decades of life. Triple arthrodesis was done in sixteen of the patients in the first decade, that is, in children nine or ten years of age. In four of these patients the triple arthrodeses were performed subsequent to tendon transfer. Several of the other patients in this series

appear to need triple arthrodeses at the present time and are awaiting the appropriate age for these procedures to be performed. Those patients beyond the second decade of life did not seem to obtain as good a result from these operations as did the children and young adults. In general, however, age did not seem to be an important factor in determining the result.

Transfer of the Extensor Hallucis Longus into the Neck of the First Metatarsal with and without Fusion of the Proximal Interphalangeal Joint of the Great Toe (Jones Operation)

In this group seventy patients were studied. Five had operations on both feet, so that a total of seventy-five feet were considered. Of this group, fifty-seven feet were given an over-all rating of 4 or 3, that is, satisfactory; and eighteen feet were rated 2 or less, and therefore, unsatisfactory. Nineteen feet were rated 4; thirty-eight, 3; thirteen, 2; three, 1; and two, 0.

FIG. 1-B

Postoperative photographs made in April 1955. Triple arthrodesis and transfer of the peronaeus longus to the middle cuneiform had been performed when the patient was ten. The power of the transplant was rated *trace*, but there was excellent balance of the foot because of the stabilization operation.

Interphalangeal Fusion

Arthrodesis of the interphalangeal joint of the great toe was done in sixty-eight of the seventy-five feet in this group. In seven patients no fusion was attempted. Internal fixation with an intramedullary Kirschner wire was employed in twenty operations. Three of these were failures. Forty-eight operations were done without internal fixation, and eight of these were failures. There were four complications. In the group in which pin fixation was used there was one recorded pin-tract infection and one instance when the pin was removed at an earlier date than had been planned because of pain. It was necessary to reoperate on two of the arthrodesed interphalangeal joints—in one foot to correct a rotatory deformity, and in the other to correct a flexion deformity at the joint.

Of those seven patients in whom no fusion was attempted, five had longitudinal division of the extensor hallucis longus tendon, one half being used as the transfer to the metatarsal neck and the other half being attached to the extensor hallucis brevis.

We found satisfactory results—ratings of 4 and 3—in a total of fifty-two of the sixty-eight feet in which the interphalangeal joint was fused. Fourteen of these patients had triple arthrodesis in addition to the surgery on the toe. Unsatisfactory results occurred in sixteen of the group of sixty-eight feet; four in this latter group had undergone triple arthrodesis as well. In the seven patients in whom no toe arthrodesis was done, five obtained a satisfactory and two an unsatisfactory outcome. There were no foot stabilizations in this group.

Relationship of Triple Arthrodesis to Transplantation of the Extensor Hallucis Longus

Eighteen arthrodeses of the mid-tarsal and subtalar joints were done in this entire series. These, for the most part, represented the most difficult feet to treat because of either

severe deformity or marked instability. In ten feet triple arthrodesis was done at the same time as transfer of the extensor hallucis longus. Eight of these had a satisfactory and two an unsatisfactory over-all result. In five instances the foot stabilization was done before the extensor hallucis longus operation, and in all five the outcome was good. In three the stabilization was done after the extensor hallucis longus transfer. The result was satisfactory in two and a failure in one. Thus in the eighteen feet in which triple arthrodesis was done there were fourteen satisfactory and four unsatisfactory results. However, none in this series represented a complete failure.

Tendons Transferred

There were forty-six patients in whom the extensor hallucis longus was transplanted

FIG. 2-A

A. N., male. Preoperative photographs made in September 1953, showing varus deformity of the right foot.

alone without any other tendon transfer. Tendon ratings for this group were 4 in thirteen feet, 3 in ten feet, 2 in six feet, 1 in five feet, and 0 in twelve feet. The over-all ratings were 4 in nine feet, 3 in twenty-three feet, 2 in nine feet, 1 in two feet, and 0 in three feet.

In eleven patients the peronaeus longus was transferred at the time of the Jones operation. Of these, a combined tendon rating of 4 was obtained in five feet; of 3, in one foot; of 2, in two feet; of 1, in one foot; and of 0, in two feet. The over-all rating was 4 in three feet; 3 in five feet; 2 in two feet; and 1 in one foot.

In nine patients the peronaeus brevis was transferred at the time of the Jones operation. Of these, a combined tendon rating of 4, 3, and 2 was obtained in three feet each; an over-all rating of 4 was obtained in four, and of 3 in five feet.

As indicated, there are more good over-all results than there are functional tendon transfers. While transferred tendons were often non-functional, their shift had removed a deforming influence with over-all benefit.

In three patients the peronaeus brevis and peronaeus longus were transplanted in combination with the extensor hallucis longus. In two of these, the end result was 3 and in one, 4. The tibialis anterior was transplanted laterally in two patients with a 3 and 4 end result respectively. Finally there were four patients in whom the extensor digitorum

longus was transplanted to the metatarsal heads of other toes together with the extensor hallucis longus. In these patients there were three ratings of 4 and one of 2. The function of the extensor hallucis longus tendon was rated 4 in two; 3 in one; 1 in three; and no function was found in three. The extensor hallucis longus, therefore, functioned satisfactorily in its new position in thirty-eight of seventy-five transfers, or 50 per cent. The peronaeus longus when transplanted with the extensor hallucis longus proved to function satisfactorily six times and was unsatisfactory five times. The over-all ratings for those feet in which both the extensor hallucis longus and the peronaeus longus were transferred show eight satisfactory and three unsatisfactory results. Transplantation of the extensor hallucis longus to the first metatarsal head and peronaeus brevis to the dorsum of the foot resulted in a satisfactorily functioning peronaeus brevis in six out of nine patients, with an over-all satisfactory rating in all nine.

When a tendon is cut within its paratenon, it will attempt to regenerate by the formation of a pseudopodium of scar tissue which advances distally along the tract of

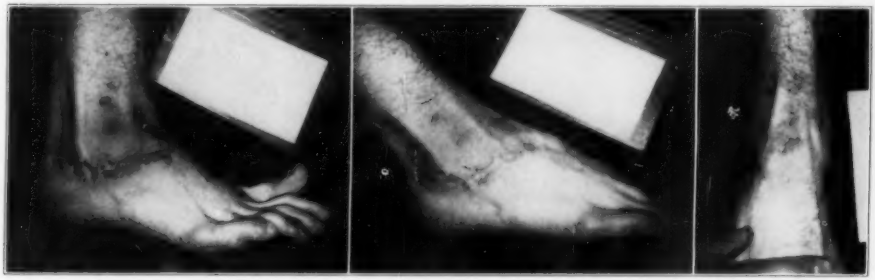

FIG. 2-B

Photographs made in March 1955, after triple arthrodesis and transfer of the tibialis posterior through the interosseous membrane to the cuboid. The patient was sixteen years old at the time of operation. The transplant was considered *fair*, functioning best in resistance with the foot in equinus. However, the result of the stabilization was excellent.

the paratenon. In this series of patients regrowth of the extensor hallucis longus to its original site occurred in ten. (Kuhlmann and Bell have reported similar findings.) In two of these reoperation was required because of recurrence of the original deformity after the tendon had become reattached. Of the whole group of ten patients, four had recurrent dropping of the first metatarsal head and five had a severely painful callus under the first metatarsal head. Two of the ten patients had transfer of the peronaeus longus at the time of transplantation of the extensor hallucis longus. In spite of the regrowth of the tendons these feet were improved and made more comfortable. In one instance the original surgery on the extensor hallucis longus had been required because of a deformity resulting from prior transplantation of the anterior tibial tendon for the correction of an equinovarus deformity.

Impressions of the Jones Procedure

Extensor hallucis longus tendon transfers proved to be functional in about 50 per cent of the patients. For cock-up deformity of the great toe alone, however, division of the tendon and fusion of the interphalangeal joint of the great toe seemed to give a generally satisfactory result. In the presence of the combined mechanism that produces the cavus tendency with dropping of the first metatarsal head and clawing of the great toe, we feel that a combined procedure will offer the best long-term result, especially if it is done at an early age and before bony deformity has become fixed. Of the nine patients in whom the peronaeus brevis was used in combination with the extensor hallucis longus,

five had persistence of dropping of the first metatarsal head, two of these with calluses under this bone. When the peronaeus longus pull was removed by transplantation of this tendon, a much better balance of the fore part of the foot appeared as far as the first metatarsal thrust was concerned. In those patients in whom transplantation of the peronaeus longus was done, either with or without the peronaeus brevis, persistent dropping of the first metatarsal head occurred in only three of fourteen patients. As would be expected, bone stabilizations were required in those patients in whom both the peronaeus brevis and the peronaeus longus were transferred in combination with the extensor hallucis longus.

FIG. 3-A

D. G., male. Preoperative photographs made in March 1942, showing calcaneovalgus deformity on the left.

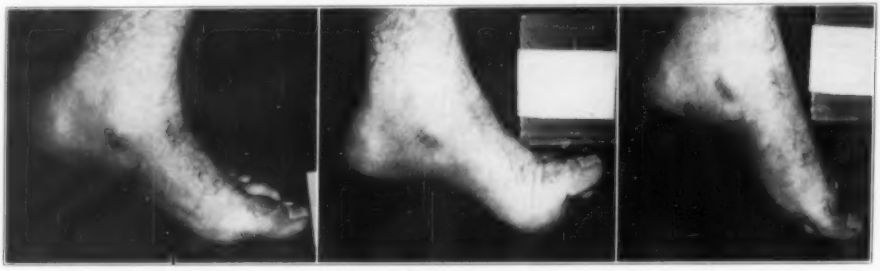

FIG. 3-B

Photographs made in March 1955, thirteen years after triple arthrodesis and transfer of the tibialis anterior through the interosseous membrane to the heel cord. Power of the transfer was rated *good* and the patient had a tenodesis effect. He had a good gait with adequate take-off.

Transplantations for Valgus Deformity Resulting from Poliomyelitis

Six operations were performed for calcaneovalgus and thirty-four, for equinovalgus. There were thirty-eight patients with forty operations. The end results are shown in Table IV. Over-all results are shown to be distinctly better than tendon-transfer function. Only eleven of the forty feet in this group showed a functioning transplant. This variance is due to the frequency of bone stabilization in the group with valgus deformity.

Thirty-two of the total of forty feet had triple arthrodesis. Of the twenty-two transfers of the peronaeus longus alone with satisfactory over-all results only six feet escaped triple arthrodesis. In the seven cases in which a functional peronaeus longus transfer was obtained, stabilization was done as part of the operation.

Comparison of Tables IV and V suggests the great importance of stabilization in the

TABLE IV

END RESULTS OF TRANSPLANTATIONS FOR VALGUS DEFORMITY

	Tendon Rating (Scale)					Over-all Rating of Foot (Scale)				
	4	3	2	1	0	4	3	2	1	0
Peronaeus longus	4	3	2	5	12	8	14	3		1
Peronaeus brevis				1	2	1	2			
Peronaeus longus and brevis	4		2	2	2	4	5	1		
Peronaeus tertius and extensor digitorum longus				1			1			

over-all results. Only one patient without stabilization had a rating of 4. In this case the tendon rating was 1 since a normal muscle had been reduced to trace by transfer. The removal of a deforming factor had achieved a good balance for the foot. In the group of patients with an over-all rating of 3, six feet did not have stabilization. The transferred tendon was less than functional in each instance. Again, the removal of a deforming influence improved these feet.

The one patient with an unsatisfactory result from combined transfer of the peronaeus longus and brevis to the dorsum of the foot has a persistent calcaneovalgus deformity. It was felt that transfers to the heel would have given greater benefit.

No function was found in any of the three patients in whom the peronaeus brevis alone was transplanted. Stabilization was done in all with eventual satisfactory outcome. The one transplant of a peronaeus tertius was feasible because this muscle was found to be of significant size and strength. It received a tendon rating of 2, but stabilization raised the over-all rating to a satisfactory level.

In summary, then, the two factors of greatest importance in the correction of valgus deformity are triple arthrodesis, to provide both stability and improvement in tendon function, and the removal of deforming peroneal power in the unbalanced foot.

Transfer Operations for Varus Deformity Resulting from Poliomyelitis

Eleven patients had a total of eleven tendon transfers for varus deformity. This is considerably less than the number of operations for valgus deformity. Most varus deformities were treated by triple arthrodesis alone. There were four patients with cavovarus, three with equinovarus, two with calcaneovarus, and two with varus of the heel and extension of the great toe.

The type of transfers and the tendon rating at the time of the end-result study are listed in Table VI.

Transfer of the tibialis anterior tendon laterally was done with good maintenance of muscle power (Table VI). One functional tendon was graded down in the over-all analysis because of a persistent calcaneus deformity. This foot requires a panarthrodesis. We felt that it would have been better to transfer the tendon to the heel cord. In addition, triple arthrodesis was later performed in five of these cases, resulting in an over-all rating of 4 in four cases and of 3 in one case.

TABLE V

OVER-ALL RATING AFTER TENDON TRANSFER AND STABILIZATION PROCEDURES IN VALGUS DEFORMITY

	Rating Scale				
	4	3	2	1	0
Peronaeus longus	7	9	2		1
Peronaeus brevis	1	2			
Peronaeus longus and brevis	4	4	1		
Peronaeus tertius and extensor digitorum longus		1			

TABLE VI

END RESULTS OF TRANSPLANTATIONS FOR VARUS DEFORMITY

	Tendon Rating (Scale)					Over-all Rating (Scale)				
	4	3	2	1	0	4	3	2	1	0
Tibialis anterior	3	2		1		3	1	1	1	
Tibialis posterior		1		1	2	2		2		
Tibialis anterior and extensor hallucis longus			1				1			

TABLE VII

TRANSPLANTATION FOR CALCANEUS DEFORMITY WITH OR WITHOUT STABILIZATION PROCEDURES

	Rating Scale				
	4	3	2	1	0
Tibialis anterior	2*				
Peronaeus longus		1*		1	
Peronaeus longus and brevis	2**		2		1†
Tibialis anterior and peronaeus longus		1			
Tibialis anterior, peronaeus brevis, and peronaeus longus		2*			

* Indicates one had triple arthrodesis; † indicates astragalectomy; ** indicates both had triple arthrodesis.

In four feet transfer of the tibialis posterior tendon to the dorsolateral aspect of the foot was done. In each instance this was done through the interosseous space. Stabilization was also done on two of these feet. One of these was performed at the same time as the transplant and gave a satisfactory result both for the tendon and for the over-all position and function of the foot. The other stabilization was done two years after the transplant. The original transplant was in a deformed foot. The result of the transplant was 0, but the patient had a functional foot which was rated at 4 because of a good stabilization. Analysis of the two transplants of the tibialis posterior which were not followed by stabilization reveals that one tendon functions only as a tenodesis and the other functions not at all.

In this small group of feet with varus deformity due to poliomyelitis, the results of transfers of tibialis posterior tendons through the interosseous space were disappointing.

There is a possibility that transfer of the tibialis anterior tendon may lead to hyperextension and cock-up of the great toe. This has happened in at least two cases and both may require a Jones procedure.

Stabilization operations provided the basis for satisfactory over-all rating in five patients. There was good tendon function in four of these feet.

The most common cause for downgrading in this group was persistent varus even after triple arthrodesis. Such a foot is considered to be unsatisfactory. Here again, the removal of a deforming factor is probably as important as the function that the tendon may assume in its new position.

Tendon Transfers for Correction of Calcaneus Deformity Resulting from Poliomyelitis

Eleven patients were reviewed with operations on twelve feet. An uncomplicated calcaneus deformity was reported preoperatively in four; calcaneovalgus in five; and calcaneovarus in three. The tendons transferred, singly and in combination, and the results of the operations are listed in Table VII.

Stabilization appeared to be a very important factor in the correction of this deform-

ity. Triple arthrodesis was done on five occasions. The results in these patients were satisfactory. We consider that five other patients will be improved by stabilization, and in each instance this has been recommended. On one occasion an astragalectomy was done in association with the transfer. The result was rated 2, largely because there was severe total involvement, and the muscle that was transferred had been subfunctional before the operation. Some calcaneus persists. In three cases the anterior tibial tendon was transferred through the interosseous membrane and was rated satisfactory in each case. The method of insertion does not seem to be as important as has been stressed elsewhere [10]. In ten cases the attachment was to the heel cord only; in two there was attachment to the calcaneus. We could see no difference in the results on this basis. These feet were immobilized in plaster for an average of ten and one-half weeks. Thereafter, the patients wore calcaneus braces or heel lifts for a period of six months to a year.

In only three of these patients is there any persistence of a calcaneus deformity. Four show truly outstanding function. While only two can actually lift the heel off the ground independently, there has been loss of the calcaneus gait in all of the patients with satisfactory results. The appearance of the feet has been enormously improved, and often a severely deforming muscle pull has been eliminated.

We feel, therefore, that the combined procedure of triple arthrodesis with transplantation to the heel cord of any strong muscle group is worth while. Generally, the operation should be done fairly early in order to prevent a severe calcaneus deformity. The stabilization can then be done at an appropriate age. The tendon should be placed at full tension with the foot in equinus. Prolonged immobilization to protect the transplant from stretching and the use of elevated heels at all times for six months after operation seems desirable. The preferred type of stabilization is a reversed Lambrinudi or a Brewster countersinking procedure, as this allows posterior displacement of the calcaneus in relation to the tibia and thus gives a longer lever arm with a better mechanical advantage to the muscle pull.

Transplantation Operations in the Correction of Club-foot

Seventeen patients who had recurrent congenital club-foot were reviewed. Muscle transplant procedures for the correction of deformities were performed on twenty-five feet. The first of these operations was done in 1938; the most recent one reviewed was done in 1953. The tibialis anterior tendon was transferred to the dorsolateral aspect of the foot in every instance but one. The patient had transfer of the extensor digitorum longus to the fifth toe for a cock-up deformity following triple arthrodesis. The tendon was not found to function. Of the remaining twenty-four feet, sixteen had a tendon rating of 4, four had a rating of 3, two a rating of 2 and two a rating of 1.

The sixteen feet rated 4 received over-all ratings of 4, representing an excellent outcome. In two additional feet ratings were raised to 4 by other surgical procedures.

CASE 1. A twelve-year-old male had transfer of the tibialis anterior tendon and a simultaneous medial stripping procedure. Although after operation the transplanted muscle had only *fair plus* power and the tendon transfer was given a 2 rating, a deforming factor had been removed and the outcome of the medial stripping improved so as to give an over-all 4 rating.

CASE 2. A man twenty-eight years old had transfer of the tibialis anterior with triple arthrodesis. Muscle strength postoperatively was good, the tendon transfer was rated 3. With a good stabilization the over-all rating was 4.

In the sixteen feet with excellent results the tendon was transplanted to the cuboid in nine, the third cuneiform in four, the fifth metatarsal in two, and the second cuneiform in one. An intra-osseous suture was used in ten cases, a Bunnell suture in four, and the loop method in two.

Stabilization was done in only two of these cases and only four times in the entire

TABLE VIII

SUMMARY OF RESULTS

	Total No. of Feet	Rating				
		Satisfactory		Unsatisfactory		
		4	3	2	1	0
Hyperextension of great toe	75	19	38	13	3	2
Valgus deformity *	40	14	21	4		1
Varus deformity *	11	4	4	3		
Calcaneus deformity *	12	4	4	2	1	1
Congenital club-foot	25	18	3	4		
Miscellaneous	12	6	3	3		
Cerebral palsy	6	3	1	2		
Total	181	68	74	31	4	4

* Deformity resulting from poliomyelitis.

series of club feet. The tendon was passed subcutaneously in nine cases rather than taking the deep course beneath the inferior extensor retinaculum which was done in seven. The anterior tibial tendon in this group of feet showed an average loss after transplantation of only 0.6 of one grade. The subcutaneous transplants seemed to retain more power than those passed beneath the retinaculum. Most of the patients had had prior treatment in the form of wedging plaster. Two had had medial stripping procedures, one at the time of operation and one at a prior operation.

In only three cases did the transplanted muscles have less than fair power. In one case graded below a functional level there was continued contracture of the heel cord. In the other two—the right and left foot on the same patient—the transplants could not be found.

It is of interest to note that while cock-up deformity of the toes postoperatively was noted in half the cases, in no case was it severe enough to require a Jones procedure. This, then, represents the best group of tendon transfers of the entire series. The factors important here are that the muscle to be transferred was normal in every case except one which had been rated good postoperatively. In each of these cases correction of the heel deformity, especially equinus, was undertaken before the transplantation.

Miscellaneous Conditions

Nine patients had transfer operations on twelve feet for the following conditions: spina bifida with meningocele, three; idiopathic cavus, two; sequelae of meningococcaemia, one; congenital absence of fibula, one; spastic or rigid flat-foot, one; and sciatic-nerve injury, one.

Four feet in three patients with spina bifida were operated upon. Brief reports on these follow.

CASE 1. This patient, aged twenty-seven, had transplantation of the extensor digitorum longus to the necks of the third and fourth metatarsals. In addition a dorsal wedge was removed from the mid-tarsal region and interphalangeal fusions were performed. Tendon strength had been rated *good* before operation but was found to be 0 after operation. With fusions and stabilization, however, the over-all rating was 4.

CASE 2. In 1946 at the age of nine the patient had a transfer of the tibialis anterior to the middle cuneiform and a triple arthrodesis. Preoperatively the tendon strength was rated *normal* and postoperatively, *trace*. In 1948 the extensor hallucis longus and the extensor digitorum longus were transferred to the heads of the first, second, third, fourth, and fifth metatarsals. Preoperatively, the strength of the extensor digitorum longus muscle was *fair* and of the extensor hallucis longus, *normal*. Postoperatively both transplants were rated *good*. The combined tendon rating was found to be 3 and the over-all rating, 4.

In the other foot the same patient had a transplantation of the extensor hallucis longus as well as a

triple arthrodesis and a Jones procedure. Muscle strength both preoperatively and postoperatively was *normal* and the tendon rating and over-all rating both were found to be 4 and the patient had an excellent valgus foot.

CASE 3. This patient, aged twenty-two, had a triple arthrodesis and, later, a Jones procedure (transfer of the extensor hallucis longus to the neck of the first metatarsal). Muscle strength preoperatively was *normal* and postoperatively, *fair minus*. Both the tendon rating and the over-all rating were 2. In spite of a good triple arthrodesis the patient had trophic ulcers and infection.

Tendon transfer may be successful in patients with spina bifida. However, opportunities for transplantation are rare in these patients and usually nothing more than bone stabilization is required.

FIG. 4-A

E. M., female. Preoperative photographs made in April 1940, showing calcaneus deformity of the left foot.

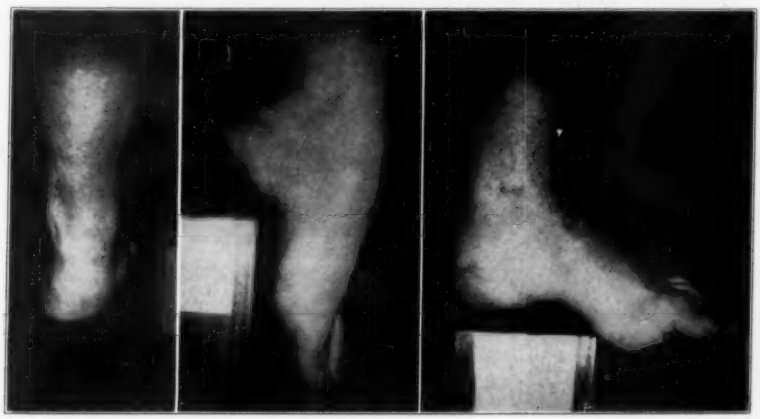

FIG. 4-B

Photographs made in March 1955, fifteen years after transfer of the tibialis anterior through the interosseous membrane to the heel cord without stabilization. A calcaneus brace had been employed for one year after operation. The muscle is now rated *good plus*.

Two patients had operations for idiopathic cavus in both feet. Their histories follow.

CASE 1. The patient at the age of fifteen had operations on both feet. In one the extensor digitorum longus was transferred to the fourth and fifth metatarsal heads. Phalangectomies were performed at a later date. Muscle strength preoperatively was *normal* and postoperatively, *fair*. The tendon rating was 2 and the over-all rating, 3.

In the other foot, the extensor digitorum longus was transferred to the second, third, and fifth metatarsal heads. Phalangectomies were performed nine months later. Muscle strength preoperatively was *normal* and postoperatively, *fair*. The tendon rating was 1 and the over-all rating, 3.

CASE 2. This patient at the age of thirty-two had operations on both feet. On one side the extensor digitorum longus was transferred to the second, fourth, and fifth metatarsal necks. Phalangectomies and, later, resections of the metatarsal heads were performed. Muscle strength preoperatively was *normal;* postoperatively, the transplantation to the neck of the second metatarsal was rated *absent* and that to the neck of the fourth and fifth metatarsals was rated *good*. Both the tendon rating and the over-all rating were 2.

In the other foot, the extensor digitorum longus was transferred to the third and fourth metatarsal necks and phalangectomies were performed. Muscle strength preoperatively was *normal* and postoperatively, *fair*. Both the tendon rating and the over-all rating were 3.

In both patients the severe cock-up deformities were relieved, but largely by removal of bone.

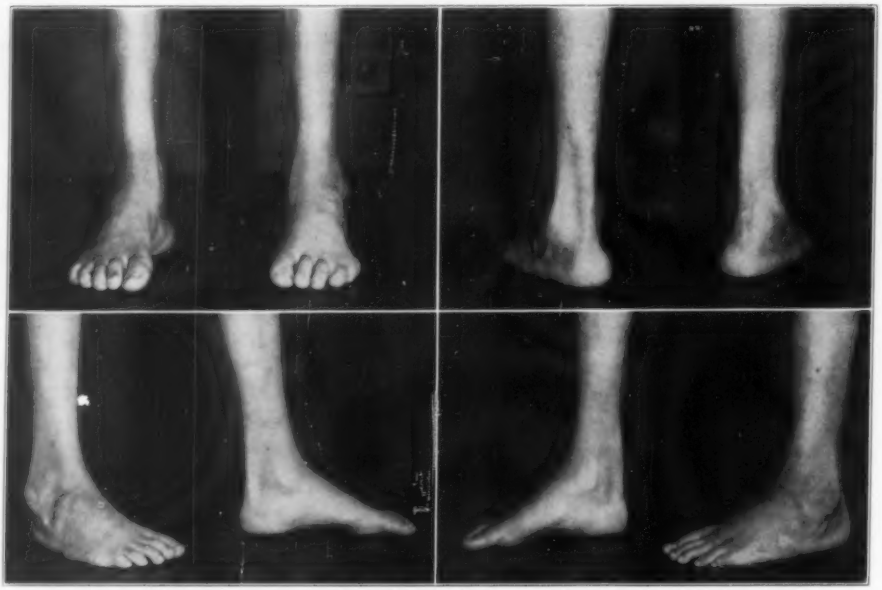

FIG. 5-A

P. S., male. Preoperative photographs made in August 1953, showing bilateral recurrent congenital club-foot.

Meningococcaemia:

A male, aged nine years, had transfer of the normal anterior tibial tendon to the cuboid for a varus deformity resulting from the local disease process. The transplant was strong and was rated at 4. The over-all rating is 3 because of continued varus.

Congenital Absence of the Fibula:

At operation in 1936, the contracted fibrous tissue in the area normally occupied by the fibula was resected. The peronaeus longus and brevis were then transferred to the neck of the talus. Before operation the strength of these muscles was in doubt; at the time of this study it was listed as *good*. The tendon rating was 4 but the over-all rating was 3 because of lateral instability. This remains a remarkable result in this difficult condition. Anterior bowing of the tibia has not occurred.

Congenital Overlapping Fifth Toe:

One patient, aged thirteen, had overlapping cock-up of the fifth toe. The extensor digitorum longus to the fifth toe was transferred to the metatarsal neck with proximal phalangectomy. The result was excellent, both the tendon and the over-all rating being 4.

Common Peroneal Nerve Lesion:

One patient, a thirty-five-year-old male, had severe equinovarus following a burn. A tibialis posterior

rated as *poor* was transferred through the interosseous membrane to the navicular and a triple arthrodesis was performed. Since the tendon rating is now *normal*, we consider the preoperative rating to be an error. There is limitation in tendon range. Both the tendon and the over-all rating are 4.

Cerebral Palsy

Transplantations were done in six patients with cerebral palsy. In five, because of equinovarus deformity, the tibialis anterior was transferred laterally, once to the lateral cuneiform and four times to the cuboid. The extensor hallucis longus was transferred in a typical Jones operation in one patient to correct a severe cock-up deformity. Muscle evaluations in these patients had been difficult preoperatively and continued to be so in our study. The Jones operation in a case of equinus with a cock-up deformity and a painful callus under the first metatarsal head was successful, except that there was partial regrowth of the tendon, and the interphalangeal fusion was not successful in that there was a fibrous union without deformity. The patient had rather severe total involvement which made the evaluation difficult.

FIG. 5-B

Photographs made in April 1955, two years after triple arthrodesis and transfer of the tibialis anterior into the third cuneiform bilaterally. The tendon transfers have normal power. They have been passed superficially to the extensor retinaculum.

A brief summary follows of the six cases in which transplantation of the tibialis anterior was done.

CASE 1. In a patient aged six the tibialis anterior was transferred to the third cuneiform. The preoperative muscle strength was not known but the postoperative strength was rated *good*. The tendon rating was 3; the over-all rating was 4, as the deforming factor was removed.

CASE 2. In a patient aged fourteen the tibialis anterior was transferred to the cuboid and a triple arthrodesis was performed. The muscle strength preoperatively was *normal* and postoperatively, *good*. Both the tendon rating and the over-all rating were 3.

CASE 3. A patient aged five and a half had transfer of the tibialis anterior to the cuboid. The preoperative muscle strength was not known and the postoperative strength was rated *fair*. The tendon rating was 3 and the over-all rating was 4; a severe varus deformity had been converted into a mild valgus deformity.

CASE 4. In another patient, aged nine, the tibialis anterior was transferred to the cuboid and a triple arthrodesis was performed. The muscle strength was *good* preoperatively and *trace* postoperatively. The tendon rating was 1 and the over-all rating, 2.

CASE 5. In a patient aged ten the tibialis was transferred to the cuboid. The muscle strength was *normal* preoperatively and *poor* postoperatively. The tendon rating was 1 and the over-all rating, 4. Although there was severe total involvement of this patient, the deforming factor in the foot was removed.

Stabilization procedures had been done on the feet in three of the cases, all with good functional results. The stabilizing procedure had improved the rating in two of the feet on which it was done but made no change in the rating in the third.

CONCLUSIONS

The method of implantation of the tendon into bone has been studied. The outcome did not seem to be appreciably affected by any of the three methods used. The degree

of tension under which a tendon was attached was found to be impossible of evaluation; however, it is our impression that a maximum degree of tension is desirable for the best result. Some transfers failed when they had to function against a fixed deformity of bone. In only one instance did a transfer produce an opposite deformity. In certain feet, especially in club feet, we were impressed by the strength of those tendons which had been passed subcutaneously rather than beneath the inferior extensor retinaculum.

Correlation of the ages of the patients at the time of operation with the operative results shows no great difference in the results of the operations done in the first decade as compared with those done in the second decade of life. Too few operations were performed in the third decade to provide figures of any value.

It is noted that the benefits derived from tendon transfer arise from the removal of a deforming factor almost as often as from the application of a positive force in a new site. Stabilization of the foot by triple arthrodesis in a good weight-bearing position has again been shown to be of considerable importance in the outcome of the average tendon transfer. Our impression is that the tibialis anterior, when normal, provides a more functional transfer than other muscles about the ankle. This was most noticeable in the patients with club-foot but was also true of the small group with residua of poliomyelitis. Transfers to the heel for calcaneus deformity resulting from poliomyelitis have proved worth while. For the most part, a satisfactory result requires osseous stabilization.

We have felt that many instances of transfer failure were due to tendon laxity at the time of the operation or to the pulling-out of the tendon attachment in the postoperative period. In the operations for club-foot, however, ten feet had excellent results from tendon transplants when the attachment was by intra-osseous suture. This is not a particularly strong suture method, and yet the outcome was good. Is there perhaps some change in tendon structure in paralytic conditions, especially in poliomyelitis, that allows for stretching in the tendon or the muscle belly?

Rating of the tibialis anterior tendon in patients with club-foot dropped only 0.6 of one grade after transfer. Is the tibialis anterior in the club-foot a better than normal muscle, or are the peroneals subnormal in their function? Both factors may be true. We have found in this very small series that the tibialis anterior function after transfer backward through the interosseous membrane was better than that of the tibialis posterior when it was transferred forward. The reason for this is not apparent.

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The Surgical Excision of Psoas Abscesses Resulting from Spinal Tuberculosis

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The purpose of this paper is to describe an operation for the excision of psoas abscesses or sinus tracts arising from tuberculous lesions of the spine and to describe the results of the operation in a group of thirteen patients (Table I). The procedure consists in the extirpation of the abscess together with any bony and cartilaginous sequestra which may be free in the tract or lodged in the diseased vertebral bodies. It is designed for use in those patients in whom treatment by simpler means has failed or is considered likely to fail because of the great size of the abscess, its chronicity, or its involvement with mixed bacterial infection. While the treatment is primarily directed at eliminating the psoas abscess, it may also be used as a means of creating a favorable environment for the healing of the osseous and cartilaginous disease which is the source of the abscess.

It has been the practice to limit the treatment of these lesions to simple aspiration or to incision and drainage when spontaneous perforation appeared to be imminent. There has been a reluctance to resort to incision and drainage because of the likelihood that the abscess would thus be converted into a permanent sinus. This reluctance has not been as pronounced since the introduction of antibiotic and drug therapy[1,2,3,5,6].

Although the operation of extirpation of the psoas abscess has been given consideration in the past, there have been few attempts to remove the lesion in its entirety and most of these attempts have resulted in failure[8]. Treves, in 1884, described an operation in which the diseased lumbar vertebral bodies were exposed through a paravertebral incision in order that bony sequestra might be removed. At the same time a drainage tube was inserted through the psoas abscess, emerging some distance from the involved vertebrae. This probably represented the limit of what could be accomplished with relative safety in the pre-antibiotic period.

The situation today is quite different from what it was prior to the introduction of antibiotics and other types of modern antibacterial drug therapy. With the protection given by the new drugs, operations may be performed upon tuberculous lesions with the same degree of safety and chances for success as operations of corresponding magnitude upon non-tuberculous lesions. The excellent results reported by Deroy and Fisher are evidence of the value of streptomycin in the treatment of tuberculous disease of the vertebrae and other bones. These observations should not be interpreted as meaning that streptomycin or other antibacterial drug therapy alone or combined with surgical treatment fulfills the requirements for the healing of tuberculous lesions of bone or other tissues. There is much to support the thesis that rest is still the most important means for obtaining long-term satisfactory results; and in the case of vertebral tuberculosis, immobilization following posterior fusion operations and adequate splinting by means of a cast and brace are recognized as essentials in satisfactory programs of treatment. What can be said definitely on the basis of experience with antibiotic and other drug therapy thus far is that these drugs act efficiently as agents for protection against dissemination of bacteria during operative procedures.

There are several reasons why the results of incision and drainage are frequently disappointing. Constrictions within the tract, tortuosity, and irregular out-pouchings all interfere with free drainage following incision or spontaneous opening. Bony and cartilagi-

TABLE I
PREOPERATIVE CONDITION

Case No.	Age and Sex	Location of Spinal Lesion	Known Duration (Years)	Extent of Abscess	Evidence for Diagnosis of Tuberculosis	Sinus	Associated Tuberculous Lesion	Previous Fusion Operation	Previous Rest Therapy	Previous Drug Therapy *
1	27 F	L4, L5	3	To left femoral triangle	+ culture from psoas abscess	1 month	Inactive pulmonary	3 years previously; firm	Bed rest 11 months; Stryker frame 3 months	Streptomycin, 42 grams
2	30 F	L1, L2	4	To left femoral triangle	+ culture from psoas abscess	1 month	Advanced active pulmonary	None	Bed rest 2 months	Streptomycin, 20 grams; PAS, 34 days
3	28 M	L4, L5	6	To left lumbar triangle	+ culture from psoas abscess	5 months	Inactive genito-urinary	None	Cast 3 months	Streptomycin, 101 grams
4	58 M	L4, L5	2	To left adductor canal	+ culture from sputum	None	Active pulmonary, genito-urinary	1 year previously; firm	Bed rest and brace 2 years	Streptomycin, 149 grams
5	27 M	L1, L2	½	To left greater trochanter	+ guinea-pig inoculation from psoas abscess	7 months	Inactive coxitis	None	Bed rest 2 months	Streptomycin, 30 grams
6	28 M	L2, L3	6	To left femoral triangle	+ culture from psoas abscess and sputum	None	Healed pleural empyema	2 years previously; incomplete	Bed rest and brace 2 years	Streptomycin, 120 grams
7	28 M	L1	3	To right femoral ring	+ guinea-pig inoculation from psoas abscess	2 years	Inactive genito-urinary	None	Cast 6 months	Streptomycin, 90 grams; PAS, 20 days
8	47 M	L4, L5, T1	3	Bilateral to femoral triangles	+ culture from psoas abscess and sputum	1 month	Active pulmonary	None	Bed rest 2 months	Streptomycin, 35 grams; PAS, 35 days
9	32 M	L3, L4	2½	Into sacral fossa	+ culture from psoas abscess	2 years	Active pulmonary, genito-urinary	None	Bed rest 18 months	Streptomycin, 137 grams; isoniazid, 18 days
10	33 M	L1, L2	3	To left femoral triangle	+ culture from sputum; cytol. study abscess wall	None	Recently active pulmonary	None	Bed rest 16 months; cast 8 months	Streptomycin, 140 grams; PAS, 5 months; isoniazid, 10 months
11	49 M	Left sacro-iliac joint	1	To left lumbar triangle	+ guinea-pig inoculation from urine; cytol. study of abscess wall	None	Active genito-urinary	1½ years previously; firm	Cast 2 months	Streptomycin, 140 grams; isoniazid, 71 days
12	61 M	L4, L5	20	Bilateral to femoral triangles	Cytol. study of abscess wall	20 years	Inactive pulmonary	22 years previously; firm	Cast 4 months; bed rest 1 month	Streptomycin, 29 grams; isoniazid, 30 days
13	28 M	L4, L5	¼	To left lumbar triangle	+ guinea-pig inoculation from abscess; culture from sputum	3 months	Inactive pleural empyema	None	Bed rest 3 months	Streptomycin, 24 grams; PAS, 30 grams; isoniazid, 60 grams

* Streptomycin: 1 gram was given intramuscularly twice a week except during the surgical period, when it was given daily. PAS: 4 grams were given orally three times a day. Isoniazid: 100 milligrams were given three times a day.

nous sequestra, which are usually present within the tract, are capable of preventing permanent healing. Often what appears to be complete healing after incision and drainage is followed months later by reopening of the sinus. We have seen several instances of recurrence following incision and drainage, but in no instance have we seen persistence or recurrence of drainage following complete removal of the sac. It is for these reasons that we prefer total excision of the sac when this can be accomplished with safety. There are occasional patients in whom not all parts of the sac can be removed because of dense adhesions in hazardous areas; in these patients curettage is used to destroy the lining membrane of the retained portions. In the several patients in whom this procedure has been resorted to, the results have been satisfactory thus far after one to several years of

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 6. Tuberculous psoas abscess originating in the first, second, and third lumbar vertebrae. This abscess extended along the psoas major, terminating at the lesser trochanter. Diodrast (70 per cent) was used as a contrast medium.

Fig. 1-B: Excised specimen.

observation; it may be, however, that permanent healing is not as likely with incomplete removal and curettage of remaining portions as it is with total excision. It is probably more than a coincidence that the only failure of healing in the group of patients operated upon was in a patient in whom an unexcised portion of the sac in the sacral fossa was not curetted.

ANATOMICAL AND PATHOLOGICAL CONSIDERATIONS

The general direction in which a tuberculous abscess of spinal origin will extend is determined by the fascia and muscles of the thoracolumbar region. Eight of the thirteen lesions in this series followed along the psoas major, reaching the lesser trochanter of the femur or extending beyond it into the Hunter's canal (Fig. 1-A). In three cases the tract extended along the iliacus (Fig. 2-A). In the remaining two cases, the abscess was bilateral, with extension to either the lumbar (Petit's) or femoral (Scarpa's) triangle (Fig. 3).

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 13. Tuberculous sinus tract originating in the diseased body of the fourth vertebra and emerging at the left lumbar triangle.

Fig. 2-B: Illustration of tuberculous caries of the fourth lumbar vertebra, with insert showing sequestra removed at time of excision of abscess.

The pathological features of the abscesses varied considerably. In some, the wall of the sac was thick throughout. In others, it was thin in some areas and thick in others. Almost all of the tracts showed constrictions and irregular branchings, and they varied from narrow sinus tracts to large sacs with a capacity of more than a liter (Fig. 1-B). In eight of the thirteen cases bony and cartilaginous sequestra were found, either free in the tract or lodged in the diseased vertebrae and intervertebral discs (Fig. 2-B). Tuberculosis was proved by culture or by inoculation of guinea pigs with pus from the abscess or sinus

FIG. 3

Case 12. Bilateral extension of a tuberculous abscess originating in the body of the fourth lumbar vertebra.

tract in nine cases. In three cases the diagnosis was made from positive cultures of the sputum or urine and in one from the histological examination of the wall of the abscess and from the patient's history of pulmonary tuberculosis. No cases with doubtful diagnoses are included in this study.

A draining sinus was present in nine of the patients. In one patient the sinus had been present twenty years, with temporary periods of closure.

PREVIOUS THERAPY

The patients in this group were all adults who were judged to have had spinal tuberculosis for some years, although the disease was not recognized in two of them until several months prior to the excision of the abscess or sinus tract. The length and intensity of previous antituberculosis therapy varied considerably and in some cases it was entirely inadequate. Poor therapy was usually the result of lack of cooperation on the part of the patient. In only two of the thirteen cases was there a history of a complete program of posterior fusion, adequate immobilization, rest, and antibacterial drug therapy. Eight of the patients had not had a posterior fusion operation prior to admission to our hospital, although the disease had been known to exist for months or years. In one patient a previous fusion operation had been unsuccessful, as indicated by roentgenograms made with the patient in various bending positions. In those patients in whom satisfactory fusion had not been obtained, the posterior fusion operation was done a few months after the débridement in order that this phase of the treatment might be carried out in the more favorable status of reduced infection.

IMMEDIATE PREPARATION FOR OPERATION

During the several weeks before operation a nutritious diet and adequate rest are prescribed in order to improve the general condition of the patient. Pulmonary, renal, or other associated tuberculous lesions are given appropriate treatment. Streptomycin (one gram daily intramuscularly) and isoniazid (100 milligrams orally three times daily) or para-aminosalicylic acid (four grams orally three times daily) are given during the surgical period, usually beginning two weeks before the operation and continuing until two weeks after the operation. After that the streptomycin is given twice a week while the dosage of the other drugs remains unchanged.

The contour and size of the lesion is determined by a roentgenographic examination in which diodrast (70 per cent) is used as a contrast medium. The examination is made by withdrawing up to fifty milliliters of pus from the abscess through a 16-gauge aspirating needle at a site of bulging of the skin and injecting a corresponding amount of diodrast while the needle remains in place. Roentgenograms are made from several angles immediately after the diodrast has been injected. In draining sinuses, the contrast medium is injected directly through the cutaneous opening. If inspissated pus prevents the radiopaque material from reaching all parts of the sac, tryptar or varidase is introduced in order to dissolve the coagulum, and the examination is repeated on the following day. The dissolving agent should not be injected into a closed abscess because of the severe febrile reaction and discomfort which is likely to result.

OPERATIVE TECHNIQUE

The operation is performed under general anaesthesia. Spinal anaesthesia should not be used because of the theoretical danger of disseminating the tuberculous infection. The surgeon and the anaesthetist should be aware of the poor general state of the patient and should avoid excessive use of sedatives, narcotics, and muscle-paralyzing drugs in the preoperative and operative medication.

The patient is placed in a position midway between supine and lateral with elevation of the trunk and flexion of the hip on the affected side (Fig. 4-A). If a sinus opening

exists, a firm 30-F rubber catheter is inserted into it to be used as a guide during the operation.

The cutaneous incision is begun at the paravertebral line just below the twelfth rib and is directed obliquely in the lumbar region midway between the twelfth rib and the crest of the ilium. It is continued in a direction parallel with and about three centimeters medial to the ligamentum inguinale and terminates five centimeters from the prominence of the pubis on the same side. The obliquus externus abdominis, obliquus internus abdominis, and transversus abdominis are incised in the direction of the fibers of the obliquus externus abdominis (Fig. 4-B), and the incision is continued for several centimeters

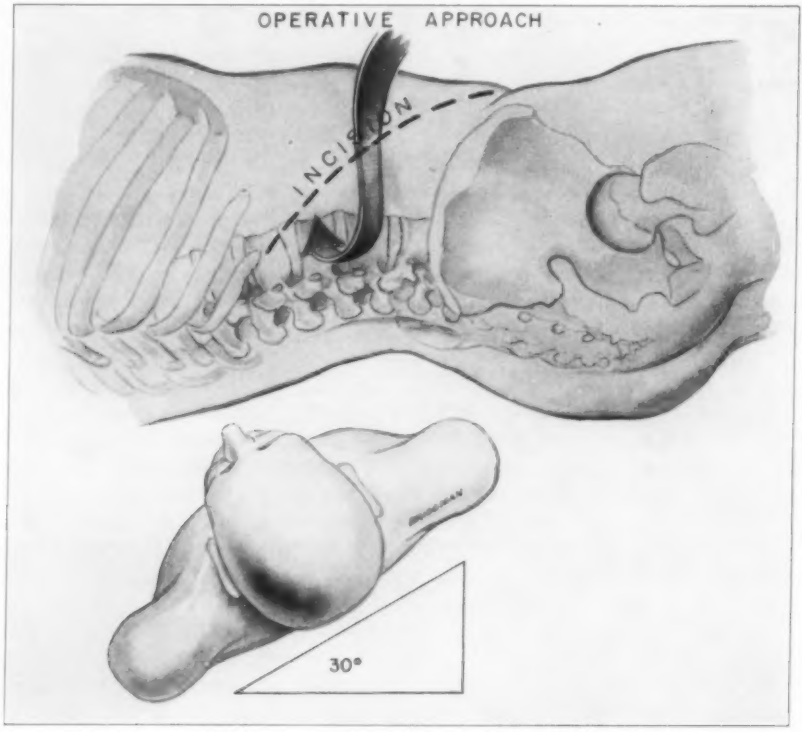

FIG. 4-A

The patient is placed on the operating table with the trunk midway between the supine and lateral positions. The course of the incision in the lumbar area is shown.

into the latissimus dorsi. Care is used to avoid the iliohypogastric and ilio-inguinal nerves as they emerge near the crest of the ilium. The transversalis fascia is now divided in order to expose the retroperitoneal space. At this stage a heavy, stable self-retaining retractor of the Finochietto type is placed in the wound so as to increase the space between the costal margin and the crest of the ilium.

The retroperitoneal space is further exposed by manual dissection in order to bring the fascial covering of the psoas major into view. The abscess, which can now be recognized by the surrounding inflammatory reaction, is exposed by incising the psoas fascia (Fig. 4-C).

The next step is the excision of the lesion (Fig. 4-D). Tracing the course of the tract is facilitated by injecting dye into its lumen before proceeding further with the dissection. Direct sky blue dye (4 per cent) serves well for this purpose. The principal structures to

be identified and protected along the upper part of the psoas major are the ureter and the spermatic or ovarian vessels. These structures usually remain intimately attached to the peritoneum while the latter is being separated from the psoas sheath in the exposure of the retroperitoneal space. Placing a catheter in the ureter helps to protect it against injury. The ureter is further safeguarded by placing an empty soft-rubber tissue (Penrose) tube around it.

The principal structure within the pelvis to be protected during the dissection is the femoral nerve, which normally lies between the iliacus and psoas major. If there is difficulty in recognizing the nerve, it is exposed beyond the area of inflammation before it is separated from the abscess. Smaller nerves, including the genitofemoral and cutaneus femoris lateralis, cannot always be recognized, but injury to them is not attended by serious consequences.

The dissection is now continued into and beyond the femoral ring as far as the abscess extends. The ligamentum inguinale may be divided in order to facilitate exposure of the region of the femoral canal. If the lesion

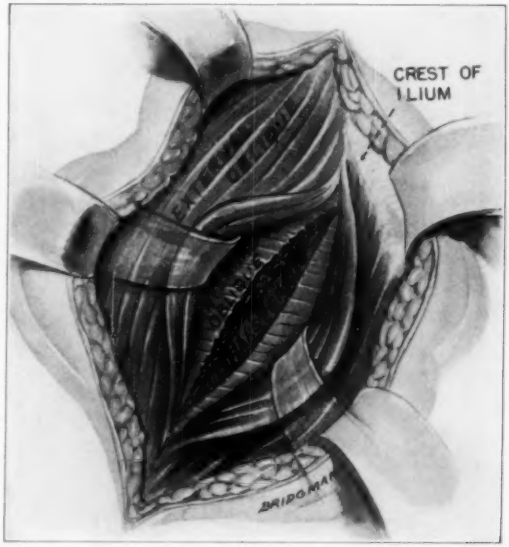

FIG. 4-B

The incision is made through the obliquus externus abdominis, obliquus internus abdominis, and transversus abdominis in the direction of the fibers of the obliquus externus.

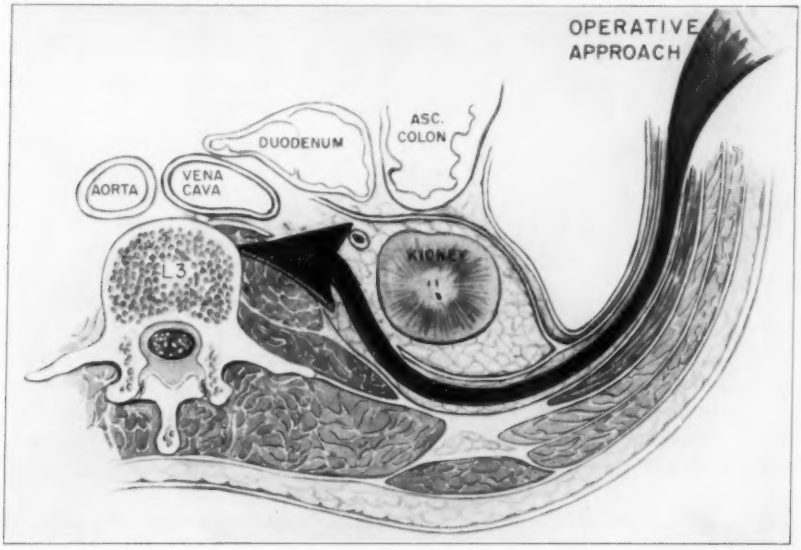

FIG. 4-C

An incision is made through the transversalis fascia in order to expose the retroperitoneal space. The psoas fascia is then incised in order to expose the tuberculous abscess and the diseased vertebral body.

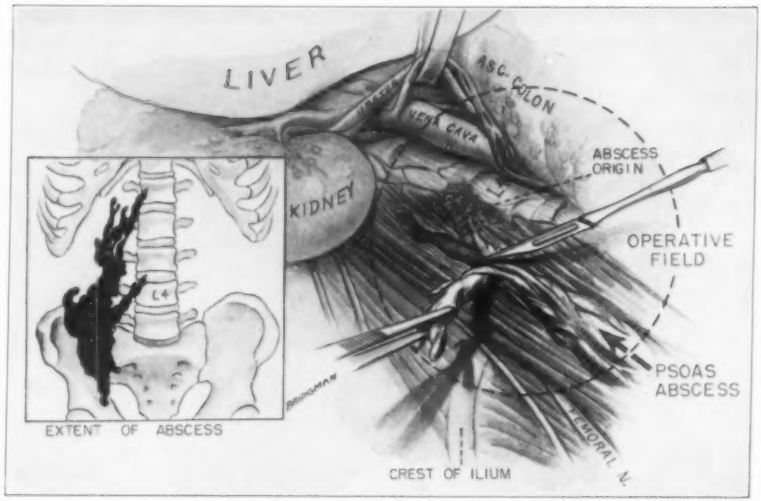

FIG. 4-D

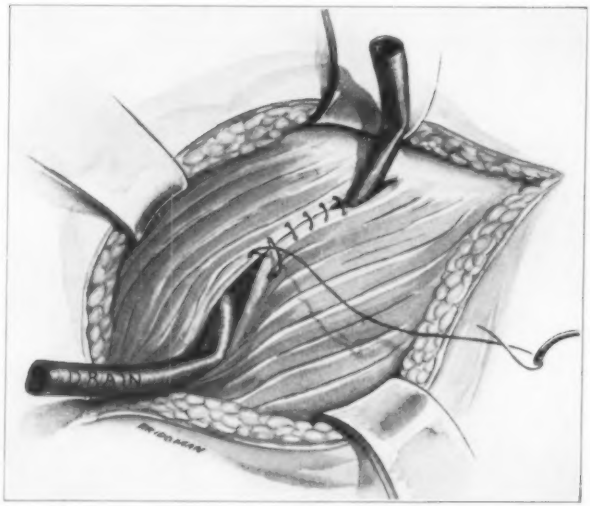

FIG. 4-E

Fig. 4-D: Excision of the abscess. The ureter, the spermatic or ovarian vessels, and the femoral nerve are the important structures to be protected in this phase of the dissection.

Fig. 4-E: Closure of the surgical wound. Temporary drains are inserted in order to avoid postoperative accumulation of serum and clot.

extends to the lesser trochanter or beyond it, a second incision is made over the femoral (Scarpa's) triangle to permit the further dissection of the tract with due regard to protection of the femoral vessels and femoral nerve. The length of the incision in the thigh is made to correspond with the extent of the abscess within the Hunter's canal.

After the sac has been excised in its entirety, the involved vertebral bodies and discs are exposed in order that the degenerated and necrotic tissues may be removed by curettage and sharp dissection. The aorta on the left side and the vena cava inferior on the right side are identified and protected during this phase of the operation. The lumbar sympathetic chain may be interrupted if it interferes with adequate exposure of the vertebral bodies.

The surgical wound is now prepared for closure. Twenty milliliters of a solution of one gram of streptomycin and 500,000 units of penicillin are instilled into the wound and soft-rubber drains are placed at the upper and lower extremities of the wound to its greatest depth. The divided fascia and muscles of the abdominal wall are closed with No. 1 chromic gut, the transversalis and obliquus internus abdominis being sutured together and the

TABLE II

OPERATION AND POSTOPERATIVE COURSE

Case No.	Date of Débridement Operation	Sequestra Removed	Fusion Operation Following Débridement	Reactivation of Spinal Disease *	Reactivation of Abscess or Sinus	Postoperative Bed Rest and Immobilization	Postoperative Drug Therapy **	Length of Follow-Up	Present General Health and Economic Status
1	7/11/49	None		None; solid fusion after 4 years	None	Cast 7 months; brace 20 months	Streptomycin, 65 grams	6½ years	Unlimited normal activity; gave birth to a child 3 years after the operation
2	10/5/49	Yes	1½ years	None; solid fusion after 4 years	None	Bed rest 24 months	Streptomycin, 71 grams; PAS, 14 days; isoniazid, 70 days	5 years	Sedentary; gained 25 pounds; active pulmonary tuberculosis
3	12/28/49	Yes	3 months	None; solid fusion after 5 years	None	Cast 7 months; bed rest 6 months	Streptomycin, 68 grams	6 years	Fully active; supports family as salesman
4	3/3/50	None		None; solid fusion after 5 years	None	Bed rest 54 months (pulmonary tuberculosis)	Streptomycin, 36 grams; PAS, 18 days	6 years	General status improved, sedentary; active pulmonary tuberculosis
5	8/4/50	Yes	9 months	None; solid fusion after 3 years	None	Brace 11 months; bed rest 6 months	Streptomycin, 214 grams; PAS, 285 days	4 years	Fully active; gained 30 pounds; supports family as salesman
6	6/21/51	Yes	5 months	None; solid fusion after 4½ years	None	Cast 6 months; brace 12 months	Streptomycin, 211 grams; PAS, 210 days	4½ years	Fully active; realtor
7	3/27/52	None	6 months	None; solid fusion after 4 years	None	Bed rest 14 months; brace 6 months	Streptomycin, 148 grams; PAS, 365 days	4 years	Fully active; student; gained 11 pounds
8	7/16/52	Yes	Refused	No roentgenographic follow-up	None	Bed rest (refused cast)	Streptomycin, 81 grams; PAS, 210 days; isoniazid, 300 days	3½ years	Guarded activity; works regularly as a fishing guide
9	9/30/53	Yes	Refused	Active after 2 years	Persistence of sinus	Cast 5 months; bed rest 22 months	Streptomycin, 200 grams; PAS, 365 days; isoniazid, 450 days	2 years	Invalided as a result of pulmonary, renal, and spinal tuberculosis
10	8/10/54	Yes	4½ months	None; solid fusion after 1⅓ years	None	Cast 3½ months; brace 12 months	Streptomycin, 88 grams; PAS, 120 days; isoniazid, 330 days	1½ years	Greatly improved, pulmonary tuberculosis arrested; works six hours a day as a salesman
11	12/16/54	None		None; solid fusion after 1 year	None	Cast 3½ months; bed rest 6 months	Streptomycin, 48 grams; isoniazid, 4 months	1 year	Good general condition; professional actor
12	2/25/55	None		None; solid fusion after ⅓ year	None	Bed rest 4 months (continuing)	Streptomycin, 102 grams; isoniazid, 8 months (continuing)	13 months	Retired; well for first time in 20 years
13	3/31/55	Yes	2 months	None; solid fusion after ¾ year	None	Cast 5½ months; brace 6 months (continuing)	Streptomycin, 102 grams; isoniazid, 300 days (continuing)	10 months	Convalescing; marked improvement; gained 24 pounds

* Spine fusion was determined by examination of roentgenograms made with the patient bending.

** Streptomycin: 1 gram was given intramuscularly twice a week except during the surgical period, when it was given daily. PAS: 4 grams were given orally three times a day. Isoniazid: 100 milligrams were orally given three times a day.

obliquus externus abdominis being sutured separately (Fig. 4-E). The skin and subcutaneous tissues are then closed with a continuous cotton suture.

The drains are removed on the second or third day. Antibiotic therapy is usually continued for a period of six months, the only change in the drug program being that streptomycin is given twice a week instead of daily beginning two weeks after operation. Complete bed rest is maintained for at least six months postoperatively, preferably with the patient in a body cast. The patient is then gradually allowed to walk while wearing a Taylor brace. He is not given permission for full ambulation until at least one year after the débridement or the posterior fusion, whichever is the most recent. In some instances this program of rest therapy was not adhered to because of failure of the patients to cooperate. However, its importance is always stressed.

In two of the recent cases (Cases 10 and 13, Table I) the space left in the diseased vertebral bodies following removal of necrotic bone was filled with bone chips after the excision of the abscess and previous to closure of the operative wound. This was done in order to obliterate the dead space within the vertebral bodies and to fuse the diseased bodies to each other.

This procedure is to be described in a later report by Dr. Richard Hall, Chief of Orthopaedics at this hospital, and will not be described here except to say that roentgenographic examinations some months after the operations have shown what appears to be filling in with bony tissue and fusion between the involved vertebral bodies. Direct fusion performed in this manner acts as an adjunct to posterior fusion.

RESULTS

Excision of the abscess and sequestrectomy have been performed in thirteen patients with known tuberculous disease (Table II). There have been no deaths. The only serious operative complication was complete severence of the femoral nerve during dissection of the pelvic portion of a sinus tract. In this patient the portion of the nerve between the psoas and iliacus was obscured by inflammatory tissue. The severence was recognized at once because of the accompanying forceful jerk of the thigh. Immediate repair by a member of the neurosurgical staff was followed by complete return of function to the quadriceps femoris.

The operation has resulted in the arrest of the disease in all but one of the patients. The one failure is accounted for by the known incomplete removal of the sac. All of the patients have gained weight and all show the general improvement in health which one would expect following the removal of an empyematic sac. Several are gainfully employed for the first time in years. These results gain significance when it is realized that all were adults in whom the disease was firmly entrenched and that a majority had had draining sinuses for months or years. In one of the patients, the sinus was known to have drained intermittently for twenty years. Coexisting active or inactive tuberculous disease in other sites was the rule rather than the exception, with pulmonary and genito-urinary lesions predominating. Ten of the thirteen patients had been previously treated by streptomycin with the addition of isoniazid or para-aminosalicylic acid or both, without favorable response. Four of the patients had firm fusion of the vertebrae of the involved region as a result of a previous operation, indicating that the suppurative lesion had progressed in the presence of a solid ankylosis. In view of the failure of previous therapy it would appear that excision of the abscess was the necessary additional factor needed to arrest the disease.

While the long-term results cannot be predicted on the basis of observations made in so few cases over a relatively short period of time, the favorable response in these patients, who have been observed for variable periods of up to six and one-half years, establishes the practical value of this procedure which is designed to heal psoas abscesses or sinuses resulting from tuberculous caries of the spine.

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End Results of Focal Débridement in Bone and Joint Tuberculosis and Its Indications

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Since the introduction of antituberculous chemotherapy, great progress has been made in the treatment of bone and joint tuberculosis, especially in the field of operative treatment. Our present problem is to select the most effective method of treatment from those now available. We have not been able to find any reports of large series in which comparative data on the results of various operative procedures have been presented; therefore, we have examined and compared statistically the results obtained by various forms of treatment in a large number of patients seen at the Orthopaedic Clinic of Kyoto University Medical School. In this way, we have tried to establish the comparative value of various methods of treatment for bone and joint tuberculosis. Special attention was paid to a method which we refer to as "focal débridement".

In our practice, focal débridement as applied to the spine (particularly the lumbosacral area) or to any major joint varies only in extent. In a major joint, all loose cartilaginous fragments, loose devitalized bone fragments, and obviously devitalized abscess materials and as much of the abscess wall as possible are removed. In the spine, all sloughed-off cartilaginous disc remnants, loose bone fragments, and abscess contents are evacuated, but the abscess wall is not removed.

The use of antituberculous chemotherapy has recently become widespread in ortho-

paedics, a development which makes it particularly essential to determine the best method of treatment: chemotherapy, surgery, or the two combined.

By means of clinical examination and correspondence we were able to determine the end results of treatment in 830 patients in a total series of 1,821 patients. There were 914 lesions in this group, including 555 (60.7 per cent) spinal caries, 132 (14.4 per cent) hip lesions, seventy-five (8.2 per cent) knee lesions, forty-three (4.7 per cent) foot lesions, forty-three (4.7 per cent) pelvic caries, nineteen (2.1 per cent) shoulder lesions, fourteen (1.5 per cent) elbow lesions, nine (1.0 per cent) wrist lesions, and twenty-four (2.6 per cent) miscellaneous lesions.

In 609 of the 830 cases a culture or tissue section of material from the bone lesion

TABLE I

COMPARISON OF RESULTS IN THE TRUNK AND IN THE EXTREMITIES

	Excellent		Good		Unimproved		Death		Total	
	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
Trunk	203	33.9	111	18.6	83	13.9	201	33.6	598	100.1
Extremities	156	49.4	56	17.7	18	5.7	86	27.2	316	100.1

TABLE II

EFFECT OF STREPTOMYCIN

	Excellent		Good		Unimproved		Death		Total	
	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
With streptomycin	139	53.1	76	29.0	35	13.4	12	4.6	262	100.1
Without streptomycin	220	33.7	91	13.9	66	10.1	275	42.2	652	99.9

under observation revealed clear evidence of tuberculosis. In a second group of eighty-four patients roentgenographic and clinical findings were positive over a long period of time and there were proved non-osseous foci of tuberculosis, but the tuberculous nature of the bone or joint lesions themselves was not definitely established by the finding of acid-fast bacillus. In a third group of 137 cases the only evidence of tuberculosis was the nature of the development of the lesion, as shown by roentgenographic and clinical examination. In the two latter groups the presence of the disease remained essentially unproved, no operations having been performed.

In this series of 830 patients, the longest period of follow-up was twenty-one years and the shortest was one year, the average period being 9.2 years. Five hundred and twenty-one patients were followed at least five years and 309 were followed less than five years.

In numerous instances poverty precluded the patient's making a return visit for personal examination by the surgeon. In 716 cases follow-up data were obtained by direct medical examination by the authors, and in 114 cases, they were obtained through questionnaires mailed to the patient or through the written reports of other examining physicians.

The criteria for evaluation were as follows: (1) excellent: convalescence completed, normal work status, and no restriction of social activities; (2) good: great improvement of local and general condition, still convalescent and under observation; (3) unimproved: deterioration or recurrence of disease; and (4) death.

TABLE III

CONSERVATIVE TREATMENT FOR SPINAL CARIES

	Excellent		Good		Unimproved		Death		Total	
	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
With streptomycin	9	20.9	17	39.6	13	30.2	4	9.3	43	100.0
Without streptomycin	101	29.1	51	14.7	46	13.3	149	42.9	347	100.0

TABLE IV

ALBEE'S OPERATION

	Excellent		Good		Unimproved		Death		Total	
	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
With streptomycin	11	35.5	9	29.0	11	35.5	0	0	31	100.0
Without streptomycin	22	44.0	8	16.0	4	8.0	16	32.0	50	100.0

TABLE V

FOCAL DÉBRIDEMENT FOR SPINAL CARIES

	Excellent		Good		Unimproved		Death		Total	
	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
With streptomycin	25	52.0	21	43.8	1	2.1	1	2.1	48	100.0
Without streptomycin	6	21.4	1	3.6	1	3.6	20	71.4	28	100.0

Long-term observations revealed that the results tended to remain stable after five years of treatment. For this reason, end results may be considered fully significant only after at least five years.

END RESULTS

The lesions were divided into two main groups, lesions of the trunk and lesions of the extremities. The results of treatment in the former group (598 cases) were inferior to those in the latter group (316 cases) (Table I).

There were definite differences in the results obtained with and without antituberculous drugs, those obtained in the 262 lesions treated by streptomycin being superior to those obtained in the 652 lesions not treated by streptomycin (Table II).

Tuberculosis of the Trunk: Spinal and Pelvic Caries

A study of the results obtained by conservative treatment, without streptomycin in 347 cases and with streptomycin in forty-three cases, revealed no marked differences, except in the death rate (Table III). We may say, therefore, that conservative treatment combined with streptomycin tends to increase the number of cases in which there is neither a complete cure nor death.

TABLE VI

CONSERVATIVE TREATMENT FOR THE EXTREMITIES

	Excellent		Good		Unimproved		Death		Total	
	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
With streptomycin	2	10.5	7	36.8	6	31.6	4	21.1	19	100.0
Without streptomycin	58	35.8	29	17.9	9	5.6	66	40.7	162	100.0

TABLE VII

FOCAL DÉBRIDEMENT FOR THE EXTREMITIES

	Excellent		Good		Unimproved		Death		Total	
	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)	(*No. of Cases*)	(*Per cent*)
With streptomycin	77	76.2	19	18.8	2	2.0	3	3.0	101	100.0
Without streptomycin	20	62.5	1	3.1	1	3.1	10	31.3	32	100.0

A study of the results obtained by Albee's operation, without streptomycin in fifty cases and with streptomycin in thirty-one cases, revealed no special effectiveness of the combined operation and streptomycin, except as regards the death rate (Table IV). It is difficult to say whether the results of Albee's operation are definitely superior to those obtained by conservative treatment.

A study of the results obtained by focal débridement, without streptomycin in twenty-eight cases and with streptomycin in forty-eight cases, demonstrated that the latter is obviously superior to the former (Table V). Focal débridement without streptomycin is a dangerous operation when it is performed for spinal caries; when performed for lesions of the extremities, however, it is not always dangerous.

In the treatment of spinal caries focal débridement with streptomycin is definitely superior to any of the other therapeutic methods mentioned, and we have found that almost the same results may be obtained in the treatment of pelvic caries.

Bone and Joint Tuberculosis of the Extremities

Conservative treatment was used without streptomycin in 162 cases and with strepto-

mycin in nineteen cases. In this series the effect of the use of the drug was not obvious, except as regards the reduction of deaths (Table VI).

The results obtained by focal débridement, without streptomycin in thirty-two cases and with streptomycin in 101 cases, indicated that the latter method is superior to the former; this was true in spite of the fact that the period of follow-up in the latter group was shorter than that in the former. In the treatment of tuberculosis of the extremities, the results of focal débridement combined with streptomycin are definitely superior to all other forms of treatment (Table VII).

INDICATIONS FOR FOCAL DÉBRIDEMENT

As our contribution to the symposium on bone and joint tuberculosis presented at the general meeting of the Japan Orthopedic Surgical Association on April 4, 1951, we reported that focal débridement is indicated during the late tranquil stage, when the disease is sometimes complicated by abscesses or sinuses. We also stated that its use may not be absolutely contra-indicated even in patients with lesions in other organs, unless the general condition of the patient is very poor.

Our later experience has confirmed these findings, and we have found no reason to change our method of treatment. However, the increasing tendency to abuse the use of chemotherapeutic agents in general has caused the development of resistant strains, which may eventually become a problem of great importance.

This may be said especially of *Mycobacterium tuberculosis*. In our series, however, we did not find any streptomycin resistance amounting to over ten gamma in the fifty-nine patients treated with up to sixty grams of streptomycin. For this reason, we feel the development of streptomycin-resistant strains can, at present, be disregarded, although, in the future, great caution should be taken against their development.

In regard to mixed infections, we consider it essential to establish adequate measures to deal with all strains of the organism prior to operation. This may be done by determining the susceptibility of the patient to specific antibiotics, whether the lesion be an infected sinus or abscess.

CONCLUSIONS

The use of antituberculous drugs in the treatment of bone and joint tuberculosis has had a definitely favorable effect. Although the maximum excellent effect of chemotherapy is not obtained when the drugs are combined with conservative (operative or non-operative) therapy, if they are combined with radical focal débridement, the results obtained are indeed remarkable.

Focal débridement is a rational form of treatment without streptomycin, but in the treatment of lesions of the trunk it is absolutely necessary to combine it with streptomycin in order to reduce to a minimum the dangers of the operation. The end results of our study show statistical evidence that focal débridement combined with streptomycin, advocated by us about six years ago, is at present the best method of treatment. The superiority of this operation can be definitely proved after the operation by the rate of healing of sinuses or abscesses, by the course of the blood sedimentation rate, and by roentgenograms.

In most of our cases in which focal débridement was done, firm bone ankylosis was the result after a period of one to two years. We are of the opinion that arthrodesis may better be performed secondarily, when needed, and that focal débridement should be done primarily.

Our experimental studies reveal that, at this time, the effect of antituberculous chemotherapy upon bone and joint tuberculosis is still confined within certain limits. We are pessimistic about the possibilities of obtaining functional restoration of tuberculous joints by arthroplasty without any recurrence of the disease, and we believe that further improvements in chemotherapy must be made before such operations will be possible.

The Results of Combined Drug Therapy and Early Fusion in Bone Tuberculosis

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This is a presentation of seventeen cases of bone tuberculosis which were treated at the Central Washington Tuberculosis Hospital after June 1, 1952. All patients admitted after that date were given, in combination, streptomycin, para-aminosalicylic acid, and isonicotinic acid hydrazide continuously and concurrently with early surgery, when indicated [1]. Resections were performed on patients with pulmonary lesions which were still positive after approximately two months of drug therapy, and on those whose disease, in our opinion, would reactivate when the drugs were discontinued. These were patients with bronchial stenosis, bronchiectasis, and caseous disease with cavities which measured two centimeters or larger. Fusion of weight-bearing joints was done in patients with bone tuberculosis as soon as the patients had improved sufficiently to be considered good surgical candidates; in these patients treatment with the three drugs was continued for six months after fusion.

MATERIAL AND METHOD

Adult patients received one gram of streptomycin sulphate intramuscularly twice a week; children under twelve years of age received 0.5 gram intramuscularly twice a week. Isonicotinic acid hydrazide was administered to patients in all age groups on the basis of four milligrams per kilogram of body weight adjusted to the nearest fifty milligram tablet; the dose was increased proportionately as the patient gained in weight. Ten grams of sodium para-aminosalicylate in solution was given daily to adults and the dosage for children was scaled down according to their weight.

Fusion was done in fifteen patients; there were twelve patients with spine lesions, and ten of these had typical destructive changes. One patient (C. M., Table III) had the dry, or sicca, form of lesion with increased density of the involved bodies. In the twelfth patient (J. B., Table III), fusion was not performed at this Hospital. This case will be discussed later. Fusion of the knee was done in three patients and fusion of the hip was done in another. Saucerization was done in a patient with cystic tuberculosis of the fibula (Table I). The average age of these patients with active bone tuberculosis was twenty-six years. The oldest patient, fifty-two years old, had a destructive lesion of the hip, and the youngest patient, one year old, had tuberculosis of the thoracic spine and an active primary source of infection. These patients were hospitalized for an average of 237 days, and they received chemotherapy for seventy-two days before they were ready for surgery. The average age of this group of patients with bone lesions was lower than the average age of patients with pulmonary disease. The average period of hospitalization of the group of patients with bone tuberculosis was almost two months longer than the average of 180 days for the patients with pulmonary disease. However, surgery was performed approximately two months sooner on patients with bone tuberculosis [3]. There were no deaths in the seventeen patients with tubercular bone disease, and no pseudarthrosis occurred. Seventy-one per cent (twelve of these patients and 78 per cent of all admissions) were Caucasian; four were Mexican and one was Indian. Ten patients were male and seven were female.

In order to illustrate some of the complications possible in bone and joint tubercu-

TABLE I

Type of Disease and No. of Cases	Average Age of Patient	Average Hospital Days	Average Days Before Surgery
Spine			
12	24 yrs.	261	84
Knee			
3	25 yrs.	197	50
Hip			
1	52 yrs.	114	33
Fibula			
1	25 yrs.	129	35
Total Averages	26 yrs.	237	72

losis, the various associated diseases we encountered in this group of patients are shown in Table II. In thirteen of the seventeen patients there was involvement of more than one system. Eleven had pulmonary tuberculosis, five had active primary infections, two had active reinfection of pulmonary tuberculosis, and four had inactive pulmonary reinfection. Two of these patients had active infections of the kidney; one, bilaterally. At operation, the left kidney of one patient (C. M., Table III) was found to be completely destroyed. This patient's urine was consistently clear and no ureteral orifice could be found when retrograde pyelograms were made; yet a culture from the urine from the destroyed kidney showed many active colonies of tubercle bacilli. The patient had received drug therapy for sixty-six days prior to the nephrectomy and for twenty-five days before spine fusion.

Diseased sinuses were present in six of the patients who underwent fusion. One patient had seven diseased sinuses when admitted; five closed after the combination of the three drugs had been used. The two sinuses which remained open were excised at the time of fusion, and microscopically, pathological changes were non-specific and there were secondary yeast-type invaders. The wounds were closed and healing occurred by primary intention. Another patient (J. B., Table III), with inactive pulmonary tuberculosis, had undergone a spine fusion elsewhere in 1940 and had had a draining sinus since that time. The patient was treated with the combined drugs for 158 days without result. The sinus was excised and a sequestrum was removed. Pathological examination proved that neither the bone nor the sinus were tuberculous. There was no pseudarthrosis and all sinuses remained closed after fusion.

We found that if a sinus did not close readily with combined chemotherapy, it was either secondarily infected or it contained a foreign body. From these pathological reports

TABLE II

OTHER ASSOCIATED DISEASE IN THIRTEEN PATIENTS WITH BONE LESIONS

	No. of cases
Active primary pulmonary tuberculosis	5
Active reinfection of pulmonary tuberculosis	2
Active renal tuberculosis	2
Inactive reinfection pulmonary tuberculosis	4
	13
Sinuses	6

TABLE III

Case	Location of Bone Lesion	Days From Admission to Surgery	Total Hospital Stay *(Days)*	Follow-up After Discharge	Occupation At Time Of Follow-up	Length Of Time On Full Activity At Follow-up	Associated Tuberculosis in Other Systems
				Spine			
*L. S.	L3, L4	166	315	35 mos.	Housewife	35 mos.	PIIA**—positive gastric
*V. T.	L5, S1	37	201	36 mos.	Bookkeeper	31 mos.	
A. M.	L1, L2	71	335	30 mos.	Retired farmer	24 mos.	PII—pleural effusion
O. M.	L4, L5	47	145	36 mos.	Farmer	30 mos.	
*C. M.	T8, 9, 10, 11, 12, L1	25	144	17 mos.	Farmer	11 mos.	Renal, kidney resected: tissue grew
*G. G.	T9, T10 Fused T8-L1	78	233	25 mos.	Housewife	25 mos.	Pleurisy with effusion
*D. G.	T5, T6, T7, T9	115	304	14 mos.	At school	24 mos.	Primary—positive gastric
*E. N.	L1, L2	26	141	15 mos.	Housewife	15 mos.	Renal bilateral, positive urine
*L. C.	L2, 3, 4	19	113	30 mos.	At school	30 mos.	Primary—lung
J. G.	T11, T12	11	409	12 mos.	At school	12 mos.	Primary—lung positive
*C. H.	T8, 9, 10	180	333	25 mos.	Pre-school	25 mos.	Primary—lung
*J. B.	Sacrum	158	211	28 mos.	Retired teacher	28 mos.	PII inactive
				Hip			
*F. S.	Left hip	33	114	28 mos.	Sign painter	14 mos.	
				Fibula			
*M. E.	Rt. fibula	34	129	none	Housewife	15 mos.	PII, inactive
				Knee			
*M. P.	Left knee	24	171	34 mos.	Housewife	34 mos.	
*B. J.	Rt. knee	86	304	40 mos.	At school	40 mos.	Primary—positive gastric
*K. S.	Rt. knee	41	200	40 mos.	Tailor	40 mos.	PI inactive
		Average 72 days	Average 237 days	Average 28 months		Average 25 months	

* See roentgenograms and case histories.

** PI —pulmonary tuberculosis, minimal.
PII —pulmonary tuberculosis, moderately advanced.
PIIA—pulmonary tuberculosis, advanced (National Tuberculosis Association classification).

it can be seen why more than 17 per cent of the material cultured for tubercle bacilli from sinuses was contaminated. Cultured material from sinuses gives the highest rate of contamination of all cultures done in our Hospital. A sinus (patient V. T., Table III) was positive for tuberculosis on pathological examination after thirty-seven days of drug therapy although all cultures had been negative. The first material aspirated from an abscess, such as a psoas abscess or an abscess of the fibula (patients L. C. and M. E., Table III), was positive both on smear and culture.

All patients who had peripheral bone and joint involvement were operated upon to establish diagnosis, and all weight-bearing joints were fused intra-articularly. These wounds healed by primary intention with no sinus formation (Table III).

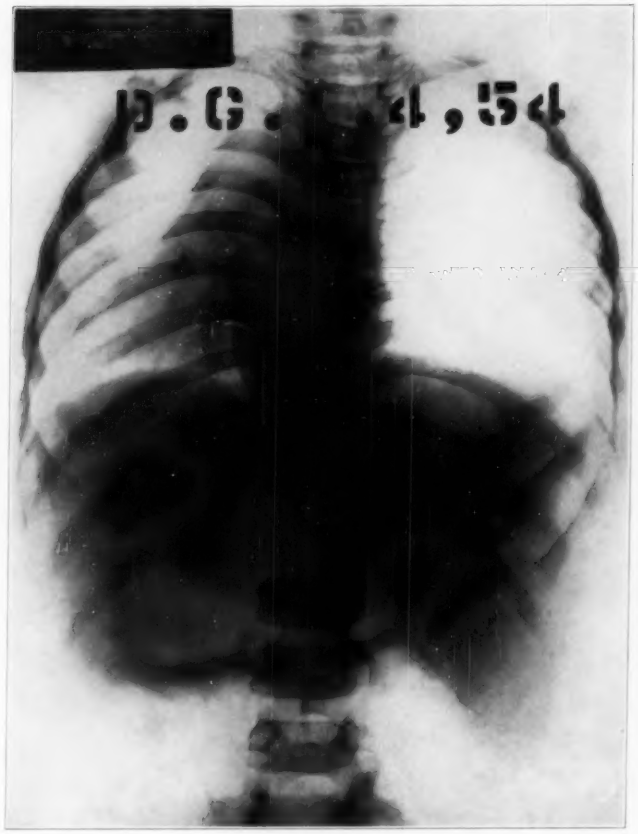

FIG. 1-A

Surgery was usually performed upon patients with bone lesions about seventy-two days after admission to the Hospital. However, sometimes there was delay and there were several reasons for this.

L. S. (Table III) had extensive miliary pulmonary disease and had been semi-invalid for four years with multiple draining sinuses. One hundred and sixty-six days of drug therapy and plaster immobilization were necessary before the toxicity of the disease subsided and the miliary pulmonary disease improved enough for the patient to be considered a good surgical risk.

Another patient, G. G. (Table III), had had an abortion just before admission to the Hospital. Profuse uterine bleeding continued and an adequate hemoglobin level could not be maintained until dilation and curettage were done. The patient's pleural effusion cleared without aspiration and spine fusion was done. She was hospitalized for 233 days. After her discharge she had an ectopic pregnancy, but at follow-up examination in August 1956, twenty-five months after her discharge, she was found to be in good general health and roentgenograms gave evidence of complete fusion of the two vertebral bodies, anteriorly and posteriorly.

Rubeola developed in two very young patients (D. G., and C. H., Table III) after admission; they were critically ill. Roentgenograms showed no improvement in either patient after three months of drug therapy and plaster immobilization. There was progression of pulmonary disease as well as of bone lesion in the twenty-month-old patient, C. H.

Roentgenograms of a four-year-old Mexican boy (D. G., Table III) made at admission on January 4, 1954, showed complete destruction of the eighth thoracic vertebra and an abscess of the fifth, sixth, seventh, and ninth thoracic vertebrae. Fusion was done 115 days after admission, bank bone being used. Gastric cultures were positive. Lateral roentgenograms made in January 1956, two years later, showed good bone fusion, no increase of deformity, and the abscess was no longer visible (Figs. 1-A, 1-B, and 1-C).

FIG. 1-B

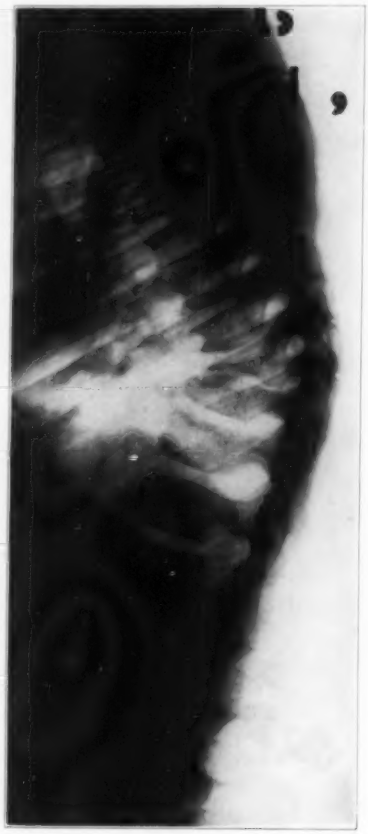

FIG. 1-C

J. B. (Table III), a woman, sixty-eight years old, had undergone spine fusion elsewhere in 1940, and since that time had had a draining sinus from the left groin. The upper lobe of her right lung was destroyed. Gastric cultures were negative at the end of six weeks of drug therapy, and, because of her age, excision of the sinus was delayed in the hope that drug therapy alone would close it.

B. J. (Table III), a three-year-old Mexican boy, had an active primary lesion in the lung and positive gastric culture. He was admitted on May 13, 1952, with his right knee fixed in the position shown in Figure 2-A. There was extensive destruction of the surface of the joint. Plaster immobilization and turnbuckle wedging was applied. Eighty-six days later, roentgenograms showed that the knee was straight (Fig. 2-B). A roentgenogram made on September 25, 1955, thirty-three months after discharge, showed open growth centers and solid bone fusion (Fig. 2-C).

Patients were usually discharged within two months after pulmonary resection and returned as out-patients for supervision. Patients with bone lesions, however, need constant nursing care as long as they are immobilized in plaster, and consequently, these required longer hospitalization. When it was known that patients' home conditions were poor, an effort was made to keep them in the hospital longer than usual. We found that small children accepted the injections of streptomycin more readily in the hospital than at home. Patients E. N., L. C., F. S., M. E., K. S., and M. P. underwent fusion, were discharged, and completed the six months' postoperative drug therapy as out-patients.

All patients except one were followed over a period of twelve to forty months; twenty-eight months was an average follow-up period. All patients have returned to their previous occupations regardless of the amount of physical activity involved. Our criteria for a

FIG. 2-A

FIG. 2-B

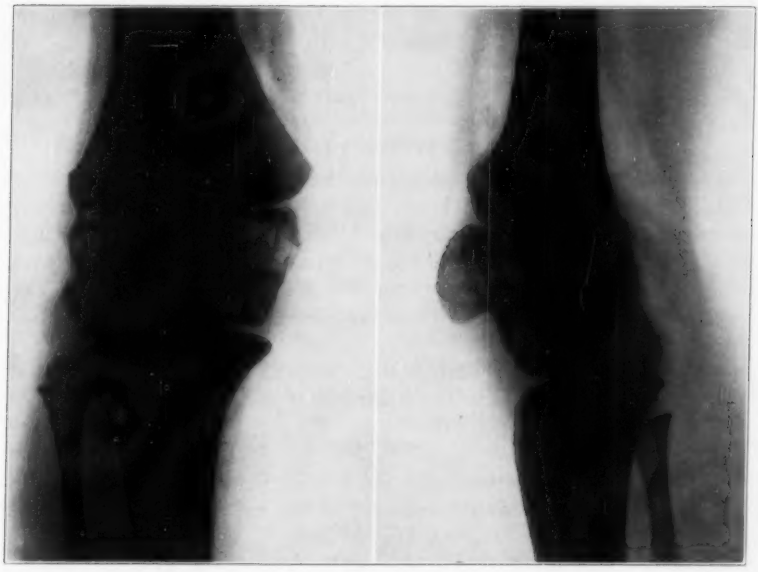

FIG. 2-C

successful result are roentgenographic evidence of bone fusion with no increase in the deformity and clinical evidence that the patients are subjectively well, with no fever, no muscle spasm or pain, no sinuses, and no motion through the site of fusion on hyperflexion, hyperextension, and lateral bending. In December 1955 and January 1956, follow-up examinations were made of eight patients with spine lesions and three patients with peripheral lesions. Gastric lavage for culture was done.

Cultures from the resected bone and cartilage of patients F. S., M. E., and K. S. (Table III) were positive for tubercle bacilli after drug therapy for thirty-three, thirty-four, and forty-one days, respectively. There was no evidence of bacilli in culture of bone and cartilage from patient M. P. However, microscopically, tuberculous changes were

FIG. 3-A

FIG. 3-B

observed. Cultured urine from a destroyed kidney which had been removed (C. M., Table III) showed the presence of tubercle bacilli. Thus, four out of five specimens cultured from patients with extrapulmonary tuberculosis were positive despite chemotherapy.

Positive cultures of caseous or cavitary material from 129 pulmonary resections, performed after an average of three to four months of drug therapy, were obtained in only 18 per cent. There was evidence of tubercle bacilli on smear in an additional 8 per cent.

From this evidence, we must conclude that chemotherapy is less effective in sterilizing extrapulmonary disease than it is in the treatment of pulmonary tuberculosis.

DISCUSSION

A diagnosis of tuberculosis was established in all patients with peripheral lesions—hip, knee, and fibula—from material removed at the time of exploration. Prior to admission, patient K. S. (Table III) had had a biopsy of the right knee done elsewhere, and the diagnosis was blastomycosis. After we had operated upon the knee, a culture was made of the tissue removed, and tubercle bacilli were found. The pathologist's diag-

nosis was tuberculosis. Fusion was done, a Smith-Petersen nail being used. The patient's clinical course after fusion bore out this diagnosis. Anterioposterior and lateral roentgenograms of the right knee made forty months after he returned to his work as a tailor showed excellent results (Figs. 3-A and 3-B).

Diagnosis of tuberculosis was established in seven of the eleven patients with involvement of the spine: two of the seven had active renal tuberculosis. In both patients, the urine was positive for tuberculosis, and in one there were positive pathological changes in the left kidney which was later resected. Three of the seven patients had pulmonary tuberculosis, two with primary tuberculosis had positive gastric cultures, and one with tuberculous reinfection with miliary spread had positive sputum. The sixth patient had a psoas abscess; positive cultures were made from the first drainage. Positive cultures were also made from the resected sinus of the seventh patient. The remaining four patients were considered tubercular on the basis of the characteristic roentgenographic findings in addition to positive Mantoux reactions. However, when Johnson and his colleagues performed biopsies on the vertebral body lesions of 407 patients, they found these criteria to be in error as much as 12 per cent [10]. They were able to make a positive diagnosis in only 22 per cent of their cases without surgical intervention. In establishing positive diagnoses without laminectomy in 70 per cent of our cases we consider our results to be above the expected average.

The fact that tuberculosis is frequently found elsewhere in the bodies of patients with bone tuberculosis is evidence of the original miliary spread of the disease. If bone lesions are not adequately treated, the infection will progress, and eventually there will be miliary spread to other organs. With simultaneous use of the three drugs, we observed no miliary or local spread of the disease even though fusion was done early in the course of treatment. Therefore, it seems logical to treat bone tuberculosis with the same drugs recommended for other types of miliary tuberculosis, such as renal tuberculosis [11] and tuberculous meningitis [8].

A modified Hibbs fusion was done in all patients with tuberculosis of the spine; bank bone was used in five small children. The bone used for fusion in the patient D. G., previously reported, was rib bone taken from another patient at pulmonary resection.

We have our own reserve of bone removed at resection. The pieces of bone are placed in sterile Mason jars, sealed, and frozen at zero degrees Fahrenheit, and stored until they are needed. About four days before the bone is to be used, it is thawed and routine cultures for secondary infections are done. Bosworth reported that when he used autogenous bone, fusion failed in 13.3 per cent of his patients after the first operation, and that when he used bank bone, fusion failed in 32.7 per cent of his patients [6]. We believe that fusion was obtained after the first operation in all our patients, including the five children in whom we used bank bone. We had no postoperative draining sinuses such as were reported by James, who also used ribs from tubercular patients as a source of bone for fusion.

Bosworth reported that of fourteen patients who had been admitted to the hospital after laminectomies performed elsewhere, only four survived; these four were patients in whom fusion was successful [4, 5]. One of our patients, V. T., a man, twenty-four years old, admitted on June 3, 1952, came to us with two draining sinuses from the lumbosacral incision for a laminectomy done elsewhere on March 12, 1952, for what was thought to be a ruptured intervertebral disc. When the disc had been exposed, green pus welled up. The wound was closed and the patient was discharged in a brace. When he was admitted to this Hospital, chemotherapy was begun and was continued for six months after fusion. Anteroposterior and lateral roentgenograms were made (Figs. 4-A and 4-B). On the thirty-seventh day after admission, July 10, 1952, a modified Hibbs fusion was done on the intact side of the vertebral bodies and the sinuses were removed. The pathologist confirmed our diagnosis of tuberculosis. The patient was immobilized in a right hip spica

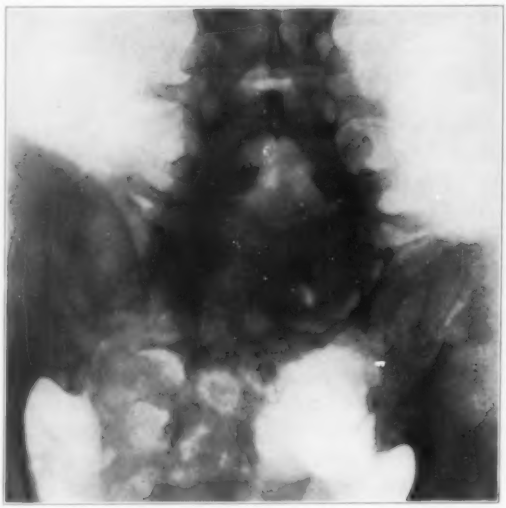

FIG. 4-A

FIG. 4-B

until September 30, 1952, at which time a brace was applied. Anteroposterior and lateral roentgenograms (Figs. 4-C and 4-D) gave evidence of early fusion. The wound healed by primary intention and treatment with chemotherapy was continued for six months after fusion; it was discontinued in January 1953. The patient was discharged on December 9, 1952, 201 days after admission. By April 1953, he was back at his job as bookkeeper for a lumber company and has continued to do well. He reports that he hunts

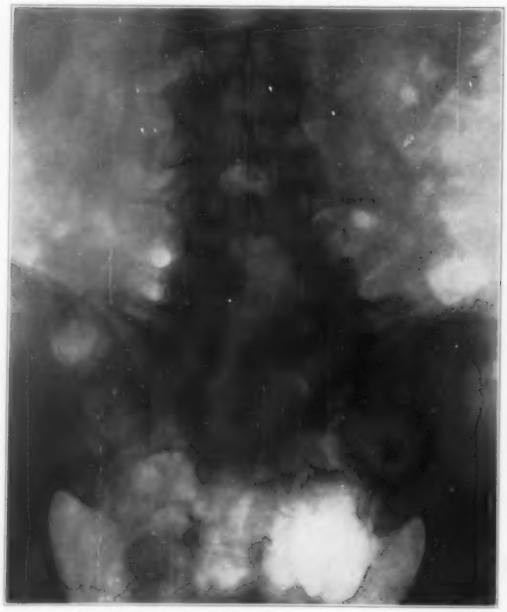

FIG. 4-C

FIG. 4-D

FIG. 4-E

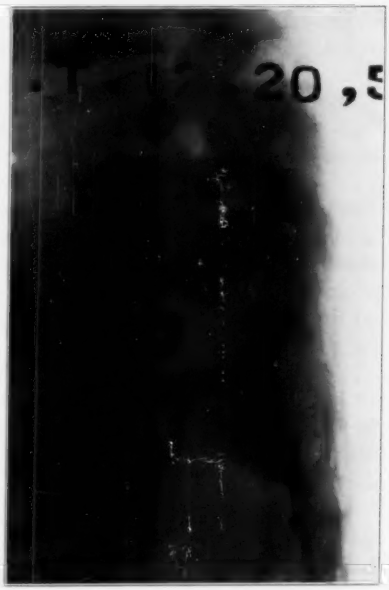

FIG. 4-F

and goes fishing as he did before his illness. Roentgenograms made on December 20, 1955, show solid fusion (Figs. 4-E and 4-F). We feel that since the patient's laminectomy prior to coming to us left only one side to fuse, the success of this operation is outstanding.

Several different techniques were used in fusion of peripheral joints in these patients, including internal fixation with a Smith-Petersen nail, external fixation with Steinmann pins, and plaster immobilization. These were all followed by primary fusion. The use of metallic fixation has been reported before by Cobey; therefore, foreign bodies are not necessarily contra-indicated, as had previously been thought.

In our exploration of involved joints, we were impressed by the fact that there was much greater destruction of the structures than was shown in roentgenograms. Because of this, we did not hesitate to open a joint to establish diagnosis. The experimental work of Mora and Llamedo has demonstrated that antituberculous drugs limit the extent of the disease but have no effect in restoring the involved bone. In three of the four patients, cultures of bone and cartilage done at the time of exploration disclosed colonies of tubercle bacilli. These findings indicate that although the antituberculous drugs hold the disease in check, the drugs do not have a sterilizing effect on tuberculous tissue of bone. Therefore, fusion alone assures stability of the joint.

We have found that by doing fusions as early as possible the growth centers are kept open in growing patients, thus preventing increased deformity, and that early fusion apparently prevents irreversible osteoporosis with its resulting complications, for these conditions have never appeared in our patients.

We have never drained an abscess deliberately; however, none of our patients were paraplegic. Abscesses resulting from involvement of the spine had decreased in size at the time of the patient's discharge.

All of our patients have returned to the work they did before their illness, regardless of the activity of the occupations. At follow-up examinations, averaging twenty-eight months after discharge from the Hospital, two men were doing farm labor, one was a

bookkeeper, another was a sign painter, one was a tailor, three were housewives, and the children of school age were back in their classes.

SUMMARY

This is an early report of a regimen of treatment in which streptomycin, para-aminosalicylic acid, and isonicotinic acid hydrazide were administered to seventeen patients with bone tuberculosis on admittance to the Hospital. These drugs were used continuously and concurrently with surgery, if indicated, until six months after surgery. Fusion seemed to be safe, even in the presence of draining sinuses, after an average of seventy-two days of chemotherapy. There were fifteen successful fusions resulting from the first operation. The period of hospitalization for the patients with bone lesions was less than a year—the average time was 237 days. There were no fatalities in the group and all the patients have returned to their former occupations.

We have found that the culture of tissue from extrapulmonary tuberculosis is positive in a large percentage of patients despite chemotherapy. Consequently, we must conclude that therapy with the three drugs is less effective in retarding the advance of extrapulmonary lesions than it is in sterilizing pulmonary tuberculosis.

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Use of Single Iliac-Bone Graft to Replace Multiple Metacarpal Loss in Dorsal Injuries of the Hand *

BY JULIAN M. BRUNER, M.D., DES MOINES, IOWA

Penetrating bullet wounds of the hand, exemplified by the classical self-inflicted bullet wound through the palm, usually result in severe damage to both sides of the hand, including the skin, tendons, and nerves. Frequently only one or two metacarpal bones are fractured, with loss of bone substance in varying degrees. The accepted treatment for this type of bone injury is restoration of each individual metacarpal by means of separate bone grafts, if this is possible, or, if it is not, by shifting of a ray, the second ray being shifted to the position of the third or the fifth to the position of the fourth.

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. Appearance of the hand when the patient was first seen at the William Beaumont General Hospital in 1945. Cicatrix on the dorsum and marked shortening due to metacarpal loss are apparent. This hand had been injured by a shell fragment.

Fig. 1-B: Abdominal tube pedicle graft applied to the dorsum of the hand.

Fig. 1-C: Hand after severance of the tube pedicle.

FIG. 1-C

Blast injuries of the dorsum of the hand, produced by an explosive force or by a projectile which, traveling along a line parallel to the back of the hand, strikes a peripheral or glancing blow, may result in large defects or in ablation of the dorsal skin and extensor tendons. The metacarpal bones may be knocked out like tenpins. However, even if three or four of the metacarpals are blasted away, the structures on the palmar side of the hand, including the skin, volar digital nerves, arterial arches, and flexor tendons, may remain intact, for they are shielded by the metacarpals and the interossei.

The purpose of this paper is to present two such cases, to outline briefly the steps required for reconstruction of the dorsum of the hand, and to point out the advantages of using a single block of iliac bone as a graft when either three adjacent or all four metacarpals have been destroyed, the palmar structures remaining intact.

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Chicago, Illinois, January 27, 1956.

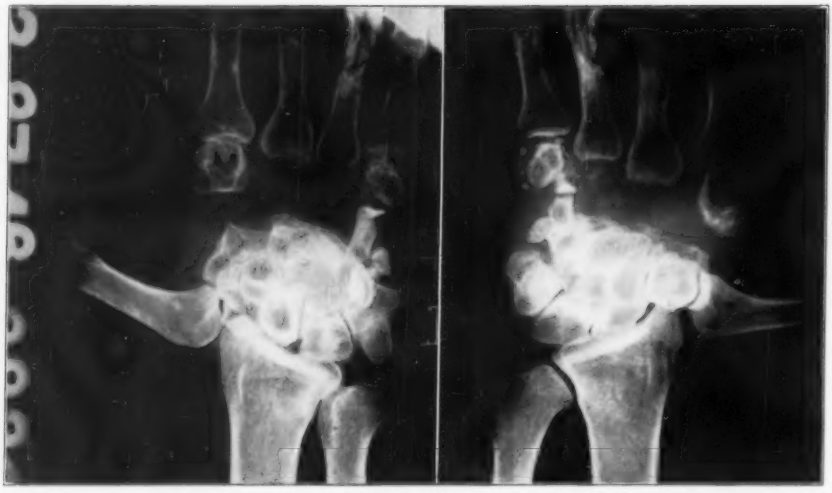

FIG. 1-D

Preoperative roentgenograms (1946) showing destruction of the second, third, fourth, and fifth metacarpals.

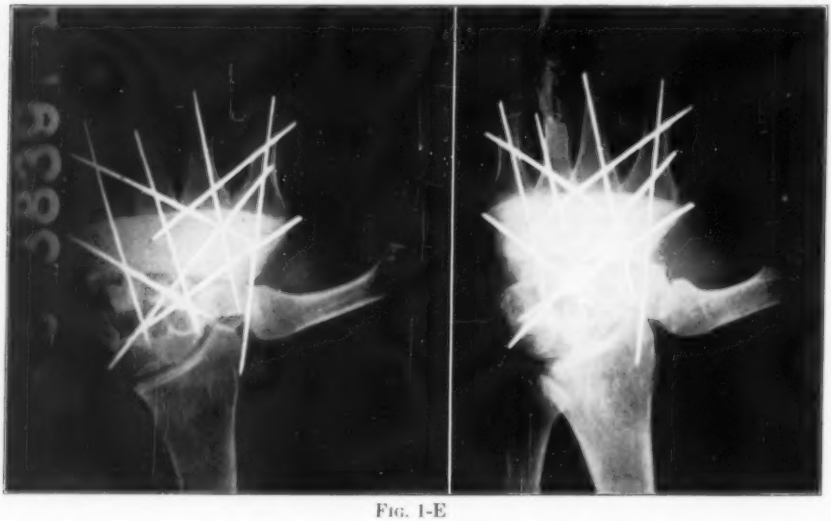

FIG. 1-E

Immediate postoperative roentgenograms showing the single block bone graft from the ilium. This graft unites the distal row of the carpal bones and the proximal phalanges of the fingers. Fixation was obtained by Kirschner wires.

CASE REPORTS

CASE 1. Sergeant A. B., twenty-six years old, was treated at the William Beaumont General Hospital, El Paso, Texas, in 1945 and 1946. He had received a shell-fragment wound on the back of the left hand during combat in December 1944. The patient was right-handed. Examination showed heavy scarring on the back of the hand, to which a split graft had been applied overseas. There was marked shortening of the hand, which was flail in the metacarpal region. The patient was unable to extend the metacarpophalangeal joints because of evident disruption of the extensor tendons of the fingers.

Roentgenograms showed virtual demolition of the second, third, fourth, and fifth metacarpal bones, only fragments remaining. The palmar surfaces of the hand and fingers were uninjured, and there was normal sensation. There was normal flexor-tendon action, but lateral movements of the fingers were markedly

FIG. 1-F

Roentgenograms made January 1956, ten years after the operation, showing solid union of the bone graft to the carpus and to the proximal phalanges of the fingers, with resulting stability of the hand.

FIG. 2-A

FIG. 2-B

Figs. 2-A through 2-G: Case 1. Present condition of the hand.

Fig. 2-A: Palmar view showing that the fingers have an incomplete but satisfactory range of extension.

Fig. 2-B: Range of flexion.

FIG. 2-C

Pinch (holding nail).

FIG. 2-D

Grasp (holding hammer).

FIG. 2-E

FIG. 2-F

FIG. 2-G

Fig. 2-E: Palmar view of both hands showing the amputation of some of the right fingers as a result of the same shell-fragment injury.

Fig. 2-F: The left hand being used to help the right hand in tying a knot.

Fig. 2-G: Patient pounding a nail (February 1956).

limited as a result of gross damage to the interossei. Voluntary extension of the interphalangeal joints was present, indicating normal action of the lumbricales.

At surgery, on October 30, 1945, the cicatrix on the dorsum of the hand was excised and was replaced by a previously constructed abdominal tube pedicle graft.

On March 12, 1946, the dorsum of the hand was re-opened, fragments of the shattered metacarpals were removed, and a single large block bone graft from the ilium was used to replace the second, third, fourth, and fifth metacarpals. Proximally, the graft was fixed by Kirschner wires to the distal row of the carpal bones, the surfaces of which had been freshly sawed away. Distally, the base of each proximal phalanx was sawed off at an angle of 130 degrees in order that the fingers might be slanted into the palm. The base of each proximal phalanx was then fixed into the distal edge of the block graft by means of Kirschner wires. Care was taken to ensure correct rotation of the fingers in the flexed position.

Since the metacarpophalangeal joints had been eliminated, it was not necessary to replace the extensor tendons. The patient could extend the interphalangeal joints by means of the intact lumbricales.

In December 1955, contact was made by letter and by phone with the patient who was then the principal of a high school in a small Texas community. He had had no further surgery on his left hand. He stated that his hand was useful in the performance of many activities. He had normal sensation, with no pain, and good stability, and he could hold and use ordinary tools.

CASE 2. D. T. H., a nine-year-old boy, was treated at the Raymond Blank Memorial Hospital and the Iowa Methodist Hospital, Des Moines, Iowa, during the years 1952 to 1955. He had sustained an accidental shotgun wound of the dorsum of the left hand. Examination showed a large defect on the back of the left hand with loss of skin and of all the extensor tendons of the fingers. There was no support for the index, middle, and ring fingers in the metacarpal region. The patient was right-handed.

Roentgenograms showed destruction of the second, third, and fourth metacarpals, only the head and neck of each metacarpal remaining. The thumb, the fifth metacarpal, and the fingers themselves were intact.

On November 23, 1952, the day of the accident, the wound was debrided of devitalized tissue and bone

fragments and was left open. It was first packed with petrolatum gauze and later was irrigated with Dakin's solution. Therapeutic doses of gas bacillus antitoxin were given intramuscularly. The appearance of the wound improved rapidly.

At surgery, on December 5, 1952, an abdominal flap pedicle graft was applied to the hand in order to close the large skin defect. Three weeks later the pedicle was severed.

On July 9, 1954, the dorsum of the hand was re-opened at the distal edge of the pedicle graft. A fan-shaped bone graft was taken from the ilium on the right side and was used to replace the second, third, and fourth metacarpals. Proximally, the graft was inserted into a transverse split in the distal edge of the distal row of carpal bones. Along the distal edge of the graft niches were made for the insertion of the necks of the second, third, and fourth metacarpals. Each metacarpal neck was then fixed into its niche in the graft in such a way that it inclined into the palm; careful attention was paid to obtaining the correct parallel position of the fingers as regards rotation.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 2. Appearance of the shotgun wound on the dorsum of the hand when the patient entered the hospital.

Fig. 3-B: Appearance of the wound fourteen days after débridement (done on the day of admission). The wound was now clean and ready for the application of an abdominal flap pedicle graft.

Fig. 3-C: Abdominal flap pedicle graft applied to the hand.

FIG. 3-C

Since the metacarpophalangeal joints of the fingers had been restored, it was necessary to replace the extensor tendons in order to provide active voluntary extension of these joints. On June 17, 1955, tendon-grafting was done. The muscles of the common extensors of the fingers were first explored. They were red and healthy, for the distal ends of their tendons had been adherent to the dorsum of the hand and had been acting as extensors of the wrist.

A four-inch gap was present in the extensor tendons of the index, middle, and ring fingers, and a one-inch gap existed in the extensor tendon of the little finger. Grafts taken from the long extensor tendons of the toes were used to provide extension of the metacarpophalangeal joints of the index, middle, and ring fingers. The extensor tendon of the little finger was also repaired by a graft.

As of January 1956, the patient had a useful hand and was able to engage in all the normal activities of a thirteen-year-old boy, including baseball. He had good sensation, no pain, good stability, and could perform the functions of pinch and grasp quite well. When he held the wrist joint straight out at 180 degrees, he could fully extend the fingers at their metacarpophalangeal joints (with the wrist in moderate dorsiflexion, he could not quite fully extend these joints).

DISCUSSION

The application of a pedicle graft in the first stage of the operation is essential to the success of the reconstruction. The use of a split-skin graft may be occasionally indicated as a preliminary measure to close the open wound, as was done in Case 1. This eliminates the grim possibility of gas gangrene developing in a hand which has been affixed to the abdominal wall. However, if the wound is thoroughly debrided, if gas bacillus antitoxin

FIG. 3-D

FIG. 3-E

Fig. 3-D: Preoperative roentgenogram (1952) showing destruction of the proximal portions of the second, third, and fourth metacarpals. (The bone fragments have been debrided.)

Fig. 3-E: Immediate postoperative roentgenogram (1954) showing the single block graft from the ilium. This graft was used to replace the proximal portions of the second, third, and fourth metacarpals. The distal edge of the graft has been notched for the insertion of the metacarpal necks. Fixation was obtained by Kirschner wires.

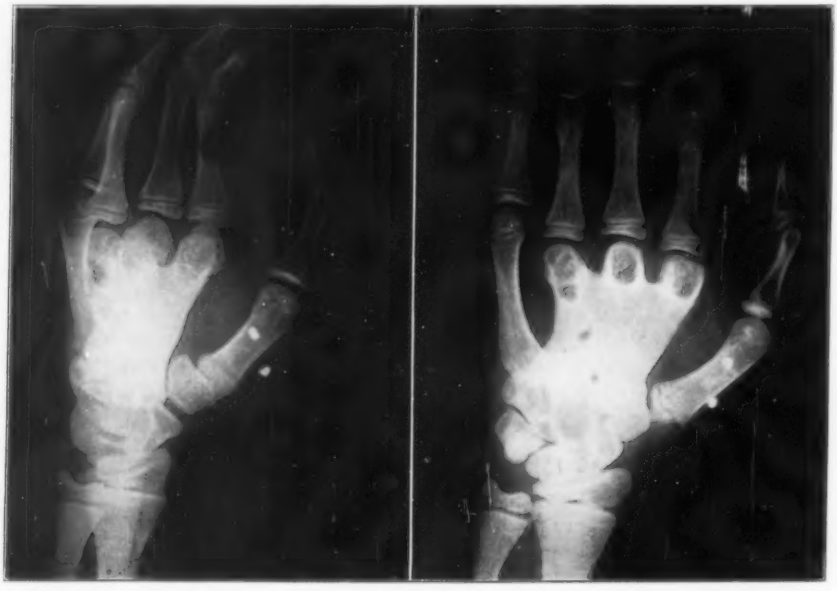

FIG. 3-F

Fig. 3-F: Roentgenograms (December 1955) showing present condition of the bone graft. Note the molding of the graft as a result of functional stresses and absorption.

FIG. 4-A

FIG. 4-B

Figs. 4-A through 4-G: Case 2. Present condition of the hand.
Fig. 4-A: Voluntary adduction of the fingers (by lumbrical action in the ring and little fingers). The wrist is supported by a book so that the fingers are free.
Fig. 4-B: Voluntary abduction of the fingers (by lumbrical action in the index and middle fingers and by abductor action in the fifth finger).

FIG. 4-C

FIG. 4-D

Fig. 4-C: When the wrist is held straight out (180 degrees), complete voluntary extension of all the fingers is possible as a result of the tendon-grafting.
Fig. 4-D: Ability of the patient to hold a pencil for writing.

FIG. 4-E

Ability to grasp a small object (pencil).

FIG. 4-F

Ability to grasp a medium-sized object (bottle).

is given in large therapeutic doses together with antibiotics, and if, in cases of doubtful safety, the wound is left open until it appears absolutely clean, a flap or tube pedicle graft may sometimes be safely applied, as it was in Case 2; this method eliminates an extra operative procedure and saves time.

Replacement of the bone framework of the hand in order to restore stability of the fingers is essential. In cases of perforating bullet wounds, the interossei may be more or less intact; in these cases reconstruction of the damaged metacarpals by means of individual bone struts is indicated. However, if the interossei have been blasted away with the metacarpal bones, there would seem to be no advantage in using individual bone grafts.

The ala ossis ilii is the ideal source for grafting material. Its natural concavity corresponds to the concavity of the palm, and its regenerative power is well known.

FIG. 4-G

Patient making a snowball (January 1956).

Although the hand is markedly shortened following loss of the metacarpals as a result of recession of the fingers, the surgeon must not attempt to restore the former length of the metacarpals by means of grafting. If an attempt is made to replace the fingers in their previous distal position, they will be fixed mechanically in a position of full extension.

If, following metacarpal injury, only the head of the metacarpal remains, it will of course be cocked-up when the finger is flexed and motion in the metacarpophalangeal joint will cease. In these fingers, it is important to carry out the bone-grafting at the earliest possible time in order to avoid complete stiffening of the joint capsules. At best, some loss of range of motion in the metacarpophalangeal joints will occur, and for this reason, at the time of bone-grafting, the metacarpal heads should be inclined toward the palm in order to permit the fingers to flex more fully into the palm.

Proper alignment of the fingers in the flexed position is most essential in order to avoid scissoring or spreading and in order to ensure the natural converging motion of the finger tips toward the navicular as they are flexed into the palm.

Restoration of normal extension of the fingers at the metacarpophalangeal joints requires healthy extensor muscles, good pedicle skin, ample subcutaneous fat through which the tendons can glide, and mobile finger joints. The long extensor tendons of the second, third, and fourth toes are ideal as a graft because of their length and their anatomical similarity to the finger extensors. This "cat-o-three-tails" may be used for the index, long, and ring fingers. The palmaris longus may be used for the little finger.

The tension of tendon grafts should slightly exceed that of the corresponding tendons in the uninvolved fingers. Although tendon grafts are said to shorten somewhat, there may be a little lengthening of the muscle itself, so that a net increase in the length of the combined muscle and tendon will probably result. In addition to this, there may be a little give at the splicing points, especially when a braiding technique of fixation has been used. Therefore, the final adjustment of the tone in a tendon graft should be, to use musical parlance, "about one-half tone sharp".

Following insertion of the extensor tendon grafts into the back of the hand, a volar plaster splint should be used to support the forearm, hand, and involved digits. The correct position of the forearm and hand is: wrist in moderate dorsiflexion and slight ulnar deviation, metacarpophalangeal joints very slightly flexed (about 170 degrees), and

interphalangeal joints in semiflexion (about 135 degrees). In some cases the uninvolved digits may be allowed a little freedom of movement even during the early weeks.

This position should be maintained for three to four weeks, after which gentle active motions of the fingers should be started. Protective splinting should be maintained for six weeks, especially at night in order to guard against overstretching of the grafts as a result of clenching of the hand during sleep.

Activation of the hand in order to restore joint mobility in the fingers following the three-week period of restraint is of extreme importance. It is of no service to the patient to restore the full range of extension in the fingers, if by so doing the full range of flexion is lost. Inability to open the hand fully is a great inconvenience, but inability to close each and every digit tightly into the palm is a serious disability.

SUMMARY

Reconstruction of two damaged hands was carried out in stages: (1) pedicle-skin grafting, (2) bone-grafting, and (3) tendon-grafting (in the second case only). In both patients, the lost metacarpals were replaced by single blocks of iliac bone, tailored to fit the size of the existing defect in the bone framework of the hand. When last seen, both patients had useful stable hands and were able to engage in many normal activities.

The natural curve of the ala ossis ilii corresponds to the concavity of the palm, and its thickness is suitable for metacarpal replacement. When either three adjacent or all four metacarpals have been destroyed, large single grafts of this type are technically easier to apply and are more stable than are multiple struts inserted to replace individual metacarpals.

NOTE: The author wishes to acknowledge the assistance of Dr. George Gill of Beaumont, Texas, in connection with Case 1 and the assistance of Dr. D. N. Gibson of Des Moines, Iowa, in connection with Case 2. He also wishes to thank Dr. Howard Smead of Des Moines, who kindly referred Patient D. T. H. to him for treatment.

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DISCUSSION

DR. RICHARD C. STAUFFER, FORT WAYNE, INDIANA: Dr. Bruner has discussed the importance of: (1) good skin coverage; (2) metacarpal replacement by means of grafting; and (3) extensor tendon-grafting as necessary. Special care should be taken during metacarpal bone-grafting to align the fingers properly. Rotation of the fingers during flexion is indeed important, and it is mandatory that good internal fixation of the grafted or transferred metacarpals be secured by Kirschner wires.

I would like to present, briefly, one case demonstrating another type of metacarpal bone-grafting. This is the case of a twenty-three-year-old Army man with shell-fragment wounds on the dorsum of the right hand. There was scarring of the dorsum with irreparable damage to the long and ring fingers. The surgery, which was done in one stage, consisted mainly in (1) scar excision, (2) amputation of the long and ring fingers, the filleted skin of both fingers being used for skin-grafting, and (3) the insertion of a cross-strut bone graft, the proximal phalanx of the long finger being used to stabilize the remaining metacarpal bones of the index and little fingers. In addition, the fifth metacarpal was shifted and derotated into the position of the fourth ray. The cross-strut bone graft and the shifted fifth metacarpal were adequately fixed by Kirschner wires. The hand was narrowed by this operation, but it was well stabilized and its function was greatly improved.

DR. GEORGE S. PHALEN, CLEVELAND, OHIO: The situation described by Dr. Bruner is not a common one, and I am sure that few of us have had extensive experience with injuries of this type. Personally, I have not had the opportunity of treating any of these injuries in private practice, but in military service we did treat similar injuries in much the same fashion as described by Dr. Bruner.

This paper serves to emphasize again the great difference between the dorsal and palmar aspects of the hand as related to reconstructive surgery. On the dorsum of the hand we do not have to worry about major nerves or about the constricting effect of tendon sheaths. Furthermore, extension of the finger is not a forceful movement. We need only restore a moderate amount of strength to the extensor muscles in order to give the patient adequate function of his hand. Then, too, one extensor tendon graft may serve for two or three fingers, if necessary.

A penetrating injury, such as is caused by gun shot going through instead of across the back of a hand, makes reconstruction of the hand a much more difficult problem. When the flexor tendons and nerves, as well as the extensor tendons and metacarpals, are destroyed, we must usually resort to amputation of the involved rays. In many such cases, sufficient vascular damage occurs to make amputation imperative anyway.

I am glad that Dr. Bruner mentioned that the extensor grafts should be inserted under tension. I think it is important that considerable tension be maintained. Gravity is constantly pulling the fingers down, and if we do not make the tendons tight, sufficient extensor power will not be obtained. It is possible, of course, to make the extensor tendons too tight, but the error is usually in the direction of insufficient tension.

I would like to have Dr. Bruner discuss the feasibility of doing arthroplasties on the proximal joints at the time of bone-grafting. I would also like him to tell us what part capsulotomy may play in cases like these. I presume Dr. Bruner is using full-thickness iliac grafts in these cases; he should clarify this detail for the benefit of the many orthopaedic surgeons who often use only the outer table of the ilium for their grafts.

Dr. Bruner (closing): In regard to arthroplasty and capsulotomy, in the second case capsulotomy might have been helpful. In children we have the best possible chance of obtaining mobile joints, even if the injured joints have not been used for some time. In some cases I am sure capsulotomy or arthroplasty might be indicated.

A full-thickness iliac graft was used in both cases.

Just one point about attempting to save time by combining stages. I believe it is rarely possible to perform bone-grafting and tendon-grafting simultaneously, as was done in a case I saw recently, for the immobility required for bone-grafting and the mobility required for tendon-grafting are incompatible.

Long-Term Results of Orthopaedic Surgery in Cerebral Palsy *

BY WINTHROP M. PHELPS, M.D., BALTIMORE, MARYLAND

During the last fifty years there has been a greatly increased effort in all fields of medicine to attempt control and correction of cerebral palsy. Because of lack of experience measures used in other crippling conditions, such as poliomyelitis, have been adapted to cerebral palsy. This has been especially true in the field of orthopaedic surgery.

This paper is an evaluation of long-term end results. In many of the procedures used, the results after one, two, or three years have appeared to be good, but as more time has elapsed changes associated with growth and maturation have invalidated these early good results.

The influence of such factors as follow-up care, efficiency of bracing, and the like on these long-term end results could not be evaluated. Undoubtedly inadequate follow-up is responsible for some poor results from procedures such as tendon lengthening. However, this is not true in the case of neurectomy. The author has observed definite evidences of the return of nerve function following these procedures, as shown by the return of clonus and other neurological signs.

The classification of cerebral palsy, formerly described by the over-all term "spastic", into clearly differentiated subgroups has helped to emphasize the fact that certain procedures successful in one type of the condition have failed in another.

In order to determine the effects of these procedures, 242 patients on whom nearly 500 operations had been performed were carefully and individually studied by the author. These patients included all those seen by the author in private practice with the exception of those in whom the history was inadequate and the type of previous surgery could not be determined. There was no selection of patients on any other basis; they were studied chronologically in a painstaking fashion and for a prolonged period of time. About half of the operations had been performed by fifty-two well known orthopaedic surgeons; in the remaining cases the name of the surgeon was not recorded. All parts of the United States are represented in this study.

The results of this survey are quite closely in accord with those reported by Pollock. In general, the results were evaluated from two points of view: (1) did the end result improve the total physical picture? and (2) was the operative procedure successful in correcting the local condition? Because of the apparently good short-term results, no evaluation was made on patients less than five years after operation, and the majority were seen ten to fifteen years after operation. While 242 patients is not a large number for an end-result study, nevertheless the trends found in this study give a clear indication as to which procedures are successful and which are not.

Each type of operation will be considered individually and the results will be evaluated separately. None of the more recent procedures will be considered, because insufficient time has elapsed for evaluation. However, the conclusions drawn from this study may help in the evaluation of these new operations since many of the latter have characteristics in common with older procedures. After consideration of all of these operations conclusions will be drawn both as to the value of specific procedures and as to the reactions of the various tissues—such as bone, tendon, muscle, and nerve—to surgery in cerebral palsy. Neurosurgical procedures are not included in this survey.

* Read at the Annual Meeting of the American Academy for Cerebral Palsy, Memphis, Tennessee, October 1955.

Some of these operations have been entirely successful in conditions resulting from poliomyelitis or other lesions of the lower motor neurons but do not seem applicable to lesions of the upper motor neurons (the spastic type of cerebral palsy). Other operations are successful in lesions affecting the pyramidal tract (spastic conditions) but are failures when applied to extrapyramidal (athetoid) lesions.

The operations reviewed were performed during the period from 1902 to 1950 inclusive; thus, the postoperative follow-up ranges from five to forty-three years. A total of 422 operations were reviewed; the results are summarized in Tables I and II.

TABLE I

Type of Involvement	No. of Operations	Improvement (*No. of Cases*)	Improvement (*Per cent*)
Spasticity	336		
Rigidity	30		
Total	366	93	25
Ataxia	5 *	5	100
Athetosis	51 **	5	9
Total	422	103	24

* All five of these were stabilization procedures.
** All of the patients in this group had operations upon bone.

TABLE II

Type of Operation	Cases Showing Improvement (*Per cent*)
Bone	90
Nerve	17
Tendon	38
Muscle transplantation	5
Miscellaneous	10

The age at which the operation was performed appeared to influence the results. Only 15 per cent of all procedures performed on patients under fourteen years resulted in improvement, while 40 per cent of those performed after age fourteen resulted in improvement.

There were 121 patients in whom heel-cord lengthening was done; the procedure was performed bilaterally in some of these. Improvement was noted in twenty-nine, or 25 per cent. The failures were found to be due to the following causes: growth of the tendon was not as rapid as growth of the bones to which it was attached; the period of postoperative fixation was too short; the dorsiflexors were spastic, resulting in calcaneus deformity; lack of power in the dorsiflexors led to recurrence of the equinus deformity because of the action of the other plantar flexors—the so-called "athetoid shift"; imbalance of the lateral muscles of the foot caused varus or valgus deformity; and finally, the severity of the general condition was such that the patient was helpless and could not benefit from any operative procedures.

Popliteal neurectomy was performed in fifty-nine patients with improvement in six or 10 per cent. The reasons for failure were as follows: recurrence of clonus due to regeneration of the nerve; spasticity of dorsiflexors resulting in a calcaneus deformity; lateral

muscle imbalance resulting in valgus or varus deformity; athetoid shift to other muscles, such as toe flexors; and severity of the general condition.

Hamstring tenotomy was performed in twenty-three patients, with improvement in fourteen, or 60 per cent. The reasons for failure were as follows: the operation had been performed too early, so that its results were invalidated by growth; uncorrected contractures of the gastrocnemius and of the hip flexors rendered the procedure ineffectual; there was no power in the quadriceps muscles to permit extension of the knees; calcaneus deformities of the foot made standing and walking impossible; changes in the weight-bearing line occurred as a result of the operation, impairing the patient's ability to stand and walk.

Adductor tenotomy was performed in forty-three patients, with improvement in ten, or 24 per cent. The reasons for failure were as follows: lack of sufficient abductor power to maintain correction; persistence of deformity due to substitution of internal rotators of the hips; inadequate postoperative fixation; abductor spasticity, causing overcorrection; persistence of deformity due to athetoid shift; changes in bone, which prevented correction of the deformity; and severity of the general condition, so that the patient was unable to benefit from the procedure.

Obturator neurectomy was performed on forty-six patients and eleven, or 24 per cent, showed improvement. The results of the intrapelvic and extrapelvic procedures were the same. The reasons for failure were: weakness of the abductor muscles of the hips; persistence of the deformity due to spasticity of the internal rotators or to athetoid shift; hip-flexion deformity due to substitution of the hip flexor muscles; and recurrence of adductor spasm due to regeneration of the nerve.

The results of osteotomies were studied in twelve cases. All were improved, although delayed union had occurred in some cases because of insufficient internal fixation and other factors. The types of procedures included were rotation osteotomies of the subtrochanteric region of the femur, as well as rotation osteotomies of the tibia, humerus, and radius; and supracondylar osteotomies of the femur to correct knee-flexion deformity.

Triple arthrodesis and other foot-stabilization procedures had been performed fifteen times with improvement in thirteen, or 86 per cent. The failures resulted from pseudarthrosis and from recurrence of equinus due to contracture of the heel cord.

Operations on the hip had been performed on fifty-five patients. In some of these dislocation of the hip had resulted from previous surgical procedures, and attempts at reduction by either closed or open methods were invariably unsuccessful. In others, however, the dislocation was presumed to be congenital in origin, occurring coincidentally with the cerebral palsy. Reduction was successful in approximately one-third of these cases. Only 60 per cent of the shelf operations were successful, failure being due to an inadequate shelf in adults and to absorption of the shelf in those children who were observed. When the operation was done after the age of fourteen, the results seemed somewhat better.

The Durham operation had been performed on eight patients. In seven of these the operation was bilateral, making a total of fifteen operations. Correction of internal rotation and good power in external rotation was obtained in only one hip; this was in a patient on whom the operation had been performed bilaterally. The reasons for failure of this operation were absence of muscle power in the external rotators, femoral torsion resulting in bony deformity, and recurrence of internal-rotation deformity because of contracture or substitution of other internal rotators as deforming factors.

Another miscellaneous group of operations may be summarized as follows: results of the Chandler operation were good unless spasticity of the rectus femoris or hamstring muscles was present. Transposition of wrist flexor tendons into the extensor tendons resulted in failure in every case. Release of the tensor fasciae latae was done only in rare instances; the results were good only if no other contracture was present and if good power

existed in the external rotators of the hip. Release of the pronator teres, on the other hand, always resulted in recurrence of contracture. The Soutter operation gave poor results unless strong hip extensors were present. Results in all cases of plantar fasciotomy were poor, and no good late results were seen after sciatic neurectomy. Alcohol injection of nerves also failed to give good permanent results, even when used in conjunction with physical therapy. Results from wrist fusion were good if sufficient power was present in the finger extensors. Thumb stabilization in spastic patients gave good results provided that all joints were stabilized. Tendon lengthening was never successful; the only exception to this was heel-cord lengthening which was found to be successful under certain conditions, to be discussed below. Muscle transplantations, such as transfers of the tibialis anterior or peronaei, were never successful unless they were combined with stabilization procedures.

DISCUSSION

Surgery for Correction of Spasticity and Rigidity

Tenotomy and Tendon Lengthening

In evaluating the results of the various surgical procedures, it is essential to consider the type of neurological lesion. In patients with spasticity or rigidity it is apparent statistically, even if it is not yet proved physiologically, that the involved tendons do not grow as fast as the bone or bones to which they are attached. The many patients seen in this study in whom heel-cord lengthening or tenotomy was done at three years of age, with a second lengthening at age seven and a third at age fourteen, are examples of this. In contrast to these are the patients over fourteen or sixteen, on whom tendon lengthenings were performed without recurrence of the contracture. Those patients who had heel-cord lengthening and who wore a brace at night throughout the period of growth had no recurrence of contracture, provided the brace was efficient and was worn consistently. Many of these patients have been followed for ten or fifteen years, and no tendency to recurrence has been observed in any of them. Since it is possible to stretch the heel cord and retain the fully stretched position by use of a night brace, no operation is necessary during the growth period. A day brace is seldom necessary, since with each step taken during the day the heel cord is stretched by the weight of the body on the extremity. Many parents have reported that in the morning the child walks on his toes, but that by afternoon he can place his heels on the floor. This indicates that it is the position of the foot in bed, or when not weight-bearing, which allows the contracture to recur. Many parents have been instructed to stretch the heel fifty times every night, but this is useless unless the patient wears a night brace, since the effect of stretching is offset by the natural equinus position of the child's foot during the night. Thus a night brace is usually necessary until the end of the growth period (about sixteen to seventeen years of age). The first cause of failure therefore lies in overlooking the effect of bone growth on the spastic tendon.

The second cause of failure of tenotomy or tendon lengthening in the patients with spasticity and rigidity is failure to ascertain the underlying power in the muscle groups antagonistic to the contracted tendons or muscles. The examiner must ask himself, "Why has this contracture taken place? Is it due to spasticity of the affected tendon? Is it due to immobility or lack of weight-bearing and subsequent gravitational effects? What is the status of the antagonists to this muscle?" A point not too well recognized in patients with spasticity is that there are many weak and even flaccid muscles, as well as spastic muscles, in a given extremity and that if, for example, a "tight"—but not necessarily spastic—adductor or heel cord is tenotomized or lengthened, contracture will recur if the antagonists are weak or inactive. Flaccidity of muscles such as may result from poliomyelitis is also seen in cerebral palsy and has often been described. Many heel-cord

lengthenings or adductor tenotomies have resulted in recurrence of deformity because these procedures were performed under the erroneous impression that the involved muscles were spastic, while actually the muscles were only tight because of muscle imbalance. A careful examination of the status of the antagonists must be made before the proper procedure can be selected. Only too often the observer is impressed by the contractural element of a deformity rather than by the weakness or inactivity of the opposing muscle groups. To give an example, an adductor tenotomy should never be performed unless at least some power can be demonstrated in the abductors.

A third cause of failure in patients with spasticity and rigidity is overcorrection of the deformity as a result of the operation. This is exemplified in those cases of heel-cord lengthening in which the result was a marked calcaneus or heel gait. Here again, the important diagnostic sign is the status of the antagonists. As has been stated, they may be weak or flaccid, or they may be spastic. Obviously, if a heel cord is lengthened in a foot with spastic dorsiflexors, the result will be a calcaneus position. Other examples less frequently seen are the "spread-eagle" or "frog" position resulting from adductor tenotomy performed in the presence of spastic abductors. (The first such case seen by the author was a patient on whom an adductor tenotomy had been performed in 1922. When the cast was removed, the patient's hips went into complete 180-degree abduction and were still in that position twenty years later.)

Another cause of failure in the patients with spasticity and rigidity is the presence of marked spasticity of the internal rotators in the hip, which may be mistaken for adductor tightness. Obviously, adductor tenotomy in these cases is ineffective and the position of internal rotation will persist. Femoral torsion must be eliminated before surgery on the internal rotator muscles or tendons—such as a Durham operation or release of the tensor fasciae femoris—is attempted. In these cases, too, the contractural status of the external rotators must be determined.

In some cases severe anteversion or retroversion is present and must be measured before surgical treatment is undertaken; otherwise, corrective procedures will result in an anterior or posterior dislocation of the hip, as has been seen frequently.

Neurectomy

Neurectomy is performed in an attempt to reduce the power of a given muscle or muscle group in order to balance opposing muscle power and thus bring about better function. In this group of operations the long-term results were failures in a high percentage of cases. Although frequently the results may be good for two or three years, after five years or more have elapsed, the nerve regenerates or substitution of other muscle actions occur, resulting in a return of the previous motor difficulty.

The author's experience, which has included simple cutting as well as removal of a section of nerve, and even avulsion of the nerve from the muscle, has shown that return of function and clonus, if present, occurred in all cases after five or more years. His experience has paralleled the results of operations performed by other surgeons.

Other causes of failure are the same as those described for tenotomy and tendon lengthening; that is, failure to evaluate the power of the antagonists, the effects of growth, and overcorrection in the presence of spastic antagonists. Several patients have been seen in whom hip dislocations have occurred within five years after intrapelvic or extrapelvic obturator neurectomies. After five years recurrence of adductor contracture was noted in several cases.

In operations such as tenotomy of the heel cord or of the adductor tendons performed after growth was complete, good permanent results were attained if the antagonists had been correctly evaluated. However, even in all these adults return of the spasticity was seen five years after neurectomy. It is the author's conviction that neurectomy of any type has no permanent value in the treatment of cerebral palsy.

Surgical Treatment of Athetosis

Athetosis has had many definitions. From the orthopaedic point of view athetosis may be defined as an involuntary attempt on the part of the body to assume a distorted position by means of any muscles which can be used to produce this position. In the athetoid patient, therefore, muscle, tendon, or nerve surgery only results in an athetoid shift to other muscles. Thus, if the heel cord is lengthened in the presence of strong extensor thrust at the ankle, the toe flexors will take over in an involuntary attempt to produce the same position, often with disabling results. Similarly if tenotomy of the adductors is performed, the internal rotators will replace the adductors, wrist flexors will replace finger flexors, et cetera.

In the treatment of athetosis, therefore, only bone surgery is of value.

Bone Surgery in Cerebral Palsy

The results observed from surgery on the bony structures have been almost uniformly good. This field of orthopaedic surgery has been successful in cerebral palsy in the past and will probably give the greatest possibility of success in the future.

The two types of bone surgery most frequently used in cerebral palsy so far have been stabilizations and osteotomies. These procedures do not bring about any change in the function of the muscles themselves, but do change their mechanical advantage. Thus, in a patient with internal-rotation deformity of the hips due to athetosis, no amount of bracing or exercises will bring about a better position, and muscle surgery will only result in an athetoid shift to other muscles, with persistence of the deformity. A subtrochanteric osteotomy below the attachment of the hip muscles will not disturb the athetosis, but will simply bring the extremity into a better position for walking without altering the athetoid position of the muscles about the hip joint.

Foot stabilization has uniformly resulted in improved function and avoids the athetoid shift which often results from tenotomies and may cause severe secondary valgus or varus deformities.

In some cases arthrodesis of the hip enabled patients to stand or walk who previously had been unable to do so. Supracondylar osteotomy of the femur in mild or moderate knee-flexion deformities has been successful. Rotary osteotomies of the radius or of the humerus for deformities of the arm have proved of lasting value when muscle lengthening or tenotomy has failed.

SUMMARY

Orthopaedic surgery has a definite place in the treatment of cerebral palsy. However, of the many surgical procedures which are successful in poliomyelitis not all are adaptable to cerebral palsy, since the characteristics of the two conditions are entirely different.

The effects of growth and consequent recurrence of deformities must be considered in evaluating the functional results. Tendon lengthenings and tenotomies are more successful after growth has been completed. They are seldom successful when performed during the period of growth unless the desired tendon length can be maintained by use of a brace.

The status of the antagonists of all muscles for which surgery is contemplated must be carefully determined.

Muscle transplantation in both spastic and athetoid patients always fails because the injury in cerebral palsy does not involve individual muscles, as in poliomyelitis or other lower motor neuron lesions, but affects total joint function or position, which is mediated through the upper motor neurons.

In spasticity there is stimulation and in athetosis, release of the upper motor neurons.

Thus good long-term results cannot be obtained from muscle transplantation in either of these conditions.

The presence of athetoid shift must be recognized. In some instances external fixation with a brace or cast can be used to determine whether a favorable or unfavorable shift would result from surgery.

Bone surgery statistically has proved highly successful and should be the basis for further development in the field of cerebral palsy. This was also Pollock's conclusion. This author also noted that among tendon procedures hamstring and adductor tenotomies produced a relatively higher incidence of successful results, thus confirming the results of this study.

It is hoped that this survey will be a guide in the development of orthopaedic surgical procedures for the treatment of cerebral palsy in the future.

REFERENCE

POLLOCK, G. A.: The Place of Orthopedic Surgery in the Treatment of Cerebral Palsy. London, British Council for the Welfare of Spastics, 1955.

Cineplasty

AN END-RESULT STUDY*

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During the Italian-Ethiopian War of 1896, Giuliano Vanghetti, an Italian physician, first conceived the idea that the residual stump muscles of an amputee might be used to operate a prosthetic device. Since that time the procedure known as cineplasty has intrigued surgeons of all nationalities. The operation has had periods of popularity with intervening years of disfavor. Up to the present time results have not been well documented, improvements in prosthetic fitting have not kept pace with improvements in surgical technique, and the specific indications and limitations of the procedure have not been clearly defined. After sixty years there is still considerable difference of opinion as to the relative importance of this highly specialized procedure in the over-all picture of rehabilitation of the amputee.

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HISTORICAL REVIEW

Vanghetti was not a surgeon. He performed experiments on chickens in an effort to determine the practicality of harnessing the muscles of a stump to a fitted prosthesis. In 1900, he persuaded his surgical colleague, Ceci of Pisa, to perform the first cineplastic amputation on a human patient. This operation and those which shortly followed were crude affairs. They created so-called loop or club motors by harnessing opposing groups of arm or forearm muscles. In the loop type the opposing tendons were sutured over the end of the stump and covered with skin. Movement of the loop of skin over the end of the stump could be made to transmit action to the prosthesis by means of a chain or lanyard. In the club type of motor two separate opposing muscle masses were isolated and covered with skin near the end of the stump, the distal two inches of bone usually having been resected. To the clubbed areas of skin and muscle were attached metal rings, which were used to transmit motion to the terminal device of the prosthetic apparatus.

The first cineplastic prosthesis was designed by the orthopaedic surgeon, Redini. The early cineplasty procedures were performed only on fresh amputations, but in about 1907, surgeons began to utilize the residual muscle function of old healed amputation stumps to transmit motion to the prosthesis. The early prostheses were extremely awkward and the functional results were poor, but the idea was attractive, and so many surgeons attempted to improve these rudimentary devices. Eventually, however, failures caused a gradual decrease in the popularity of the cineplasty procedure.

During World War I, a radical change in the surgical technique of cineplasty was introduced by Ferdinand Sauerbruch, who was then working in Zurich. This surgeon constructed skin-lined tunnels within the arm, forearm, and thoracic muscles in order to better utilize the dynamic forces in these muscles and to provide more effective prosthetic control. This technique, together with such modifications as those advocated by Lebsche, remains in use to this time. During World War I, many hundreds of cineplasties were performed by German and other European surgeons. The improvement in operative technique made by Sauerbruch was not paralleled by a similar improvement in the design of prosthetic appliances, however, and again the enthusiasm for cineplasty waned. Between the World Wars there were few cineplasties performed, except by such enthusiasts as Kessler [14–16] and certain European surgeons. Most surgeons simply did not consider the procedure practical for the large majority of amputee patients, and cineplastic prosthetic fitting, therefore, received scant attention.

In 1931, Krukenberg introduced the technique of constructing a forceps-like probing device from the two forearm bones and their attached muscles. This had the advantage of preserving sensation in the grasping mechanism and was used principally in blind patients with forearm amputations. Although many of these were performed in Germany after World War I [10], the result has always been considered aesthetically unacceptable and the operation has never gained any degree of popularity. It is a form of cineplasty which is principally of historical interest.

Following World War II and during the Korean conflict, there were again increasing numbers of amputees, and prosthetic research assumed an entirely new and progressive outlook. As part of the program to improve the surgical treatment, training, fitting, and rehabilitation of the amputee, further attention was directed to the role of the cineplastic amputation. Although the method had been used previously in large numbers of amputees, there was still little information regarding the actual end results and there was no definite or generally accepted theory as to the proper indications for the procedure. The advantages of the various levels were not yet clearly established and the limitations of the method had not been properly demonstrated.

Cineplasty studies were instituted at the University of California at Los Angeles [5, 21], the Navy Amputation Center at Mare Island (now at Oakland), and the Walter Reed

Army Medical Center. Research on muscle physiology and mechanics in relation to cineplasty was begun, new light-weight plastic prostheses were devised, and new methods of harnessing and transmitting the muscle force to the artificial hook or hand were developed. One important improvement was the introduction of the Army Prosthetic Research Laboratory (APRL) voluntary-closing hook and hand. This device, when connected to the cineplastic muscle tunnel, gave the amputee an improved sense of position and enabled him to apply controlled graduated pressure to the fingers of the terminal device. It also enabled him to obtain active prehension by the more natural function of muscle contraction rather than by muscle relaxation. American surgeons began to take a greater interest in cineplasty surgery, and prosthetists were slowly persuaded that fitting could be satisfactorily accomplished with most advantageous results in properly selected patients. Nevertheless, because of past enthusiasm and subsequent failure and disappointment, there was still considerable reserve. Most of those interested in amputee rehabilitation maintained an attitude of guarded skepticism.

The functional results of cineplasty previously reported in the literature have been fragmentary. In 1925, Pürckhauer reported a follow-up study of sixty-eight patients upon whom cineplasties had been performed by the Sauerbruch technique. Only twenty-one of these were still using their tunnels, and they were chiefly so-called white-collar men whose work required no heavy use of their prostheses. The majority discontinued use of their tunnels because of suppuration, pain, or loss of strength. Kessler, in 1939, quoted Jottkowitz to the effect that 37 per cent of the latter's 729 patients continued to use their prostheses successfully. In 1946, the Australians, Rank and Henderson, reported a series of twelve patients with forearm amputations and stated that all were wearing their cineplastic prostheses with enthusiasm. These authors quoted Kessler as stating that 60 per cent of his 264 patients had continued routine use of their cineplastic prostheses. Rank and Henderson also stated that "in the Sauerbruch clinic 60 per cent of 304 cases are recorded as satisfied". In 1950, Finesilver reported that of seventeen patients treated by forearm cineplasty, ten were wearing their cineplastic prostheses constantly and four others were using them part time.

PRESENT STUDY

Our present study began as part of an attempt to determine the true value of the cineplasty procedure and to develop any advantages it might possess. At Walter Reed Army Medical Center, starting in 1948, the combined skills of the Orthopaedic Service, the Physical Medicine Service, and the Army Prosthetics Research Laboratory were employed in a careful appraisal of cineplastic techniques. This report is the result of the combined study during the six-year period from 1948 through 1953. It is a practical analysis of end results and does not include the associated basic physiological and mechanical investigations which were concurrently carried out and which either have been or will be reported elsewhere.

During this six-year period, a total of 108 biceps cineplasties and forty-two pectoral cineplasties were performed. In all the patients laminated plastic sockets and plastic arms were used and the muscle motor was harnessed to the terminal device. Although a few forearm, latissimus dorsi, and even quadriceps tunnels were constructed during this time, the present evaluation is limited to the biceps and pectoral cineplasties, since these areas are acknowledged to be the best suited to the procedure. As the study proceeded, there was continued improvement in surgical technique, patient selection, and prosthetic fitting; for this reason the results were divided in two groups, those obtained in the first half of the study period, and those obtained in the second half. The minimal postoperative period of follow-up was one year. A few patients had a personal interview and physical examination, but the great majority responded by mail to a detailed questionnaire. This is acknowledged to be a salient criticism of our evaluation of the results.

ANALYSIS OF RESULTS

General Aspects

It was our intention in this study to collect information regarding surgery, prosthetic training, and cineplastic fitting in order to determine the indications and limitations of the cineplasty procedure. In our evaluation we used the records of the patient's hospital course and his answers to our questionnaire. Some of our statistical data were based on our own interpretation of the patient's progress, and some were based entirely on his observations and opinions.

Our criterion for the success of the cineplasty procedure was whether or not the patient was using his prosthesis at the end of a year or more. Success of the surgery, satisfaction with the course of training, and suitability of the prosthetic device do not

TABLE I

PATIENTS WEARING CINEPLASTY PROSTHESES
COMPARISON OF RESULTS OBTAINED IN FIRST AND SECOND HALVES OF STUDY

	Total	1948–1950	1951–1953
Total group	107	22	85
Wearers	66 (61.7%)	9 (40.9%)	57 (67.1%)
Biceps cineplasty	78	17	61
Wearers	57 (73.1%)	8 (47.1%)	49 (80.3%)
Pectoral cineplasty	29	5	24
Wearers	9 (31.0%)	1 (20.0%)	8 (33.3%)

mean that the patient will continue to wear his prosthesis, which, after all, is the only purpose of the procedure. Each of these aspects will be considered separately, but the question of primary importance is whether or not the appliance was used.

Of the 150 biceps and pectoral cineplasties performed during the six-year period, the functional results of only 107 (71.3 per cent) were known. These included seventy-eight biceps operations and twenty-nine pectoral operations. The age of the patients ranged from five to thirty-nine years, the average age being 23.5 years. Only two patients in this group were children. Both of these had pectoral cineplasties, and neither was wearing his prosthesis at the end of a year. Fifty-eight cineplasties were on the left side, and forty-nine were on the right side. All the patients were males, and there was one patient with bilateral long below-the-elbow biceps cineplasties.

Success of the Procedure

It should again be emphasized that to us success means that the patient is wearing his cineplastic prosthesis regularly. Part-time use is not considered a successful result. At the end of a year or more, sixty-six (61.7 per cent) of our patients were using their prostheses regularly. There were fifty-seven (73.1 per cent) in the biceps-cineplasty group and only nine (31.0 per cent) in the pectoral-cineplasty group. Since it was apparent that better selection of patients and improvement in technique meant that better results were obtained in the patients operated on at a later date, the series was divided in two groups according to the time of operation (Table I). The results in the 1951-to-1953 group are considered to be a fair estimate of what can be expected from biceps and pectoral cineplasty at its present stage of development: only 80.3 per cent of patients with biceps cineplasty and 33.3 per cent of patients with pectoral cineplasty can be expected to continue to wear their prostheses after a year despite a greater degree of apparent success at the time of discharge from the hospital.

The relationship between the success of the cineplasty procedure and the level

of amputation is noted in Table II. In the group treated by biceps cineplasty there was little difference in the success obtained at the various levels, and even among the patients with short below-the-elbow stumps the percentage of wearers was relatively high. In the pectoral-cineplasty group, however, the patients with long stumps did only fairly well, while among the patients with short above-the-elbow stumps—a level which would seem most appropriate for cineplasty—the percentage of wearers was only 14.3.

It seemed desirable to compare the end results obtained by the cineplasty procedure with those obtained by conventional methods and light-weight plastic prostheses during the same period of time. We could locate seventy-six such patients. The results of this

TABLE II

WEARING OF PROSTHESIS IN RELATION TO LEVEL OF AMPUTATION

	No. of Patients
Biceps Cineplasty	
Long above-the-elbow stumps	12
Wearers	8 (66.6%)
Long below-the-elbow stumps	60
Wearers	44 (73.3%)
Short below-the-elbow stumps	6
Wearers	5 (83.3%)
Pectoral Cineplasty	
Long above-the-elbow stumps	15
Wearers	7 (46.7%)
Short above-the-elbow stumps	14
Wearers	2 (14.3%)

TABLE III

COMPARISON OF END RESULTS

	Patients with Cineplastic Prosthesis	Patients with Conventional Prosthesis
Total group	107	76
Wearers	66 (61.7%)	63 (82.9%)
Below-the-elbow amputees	66	42
Wearers	49 (74.2%)	39 (92.9%)
Long above-the-elbow amputees	27	10
Wearers	15 (55.6%)	6 (60.0%)
Short above-the-elbow amputees	14	24
Wearers	2 (14.3%)	18 (75.0%)

study are shown in Table III. It will be noted that, at any level, the percentage of conventionally fitted amputees who were wearing their prostheses at the end of a year or more was considerably higher than the percentage of cineplastic patients who were still wearing their prostheses. The difference is least marked in the patients with biceps cineplasty and most pronounced in the amputees with short above-the-elbow stumps, the group in which, theoretically, there is the greatest need for cineplasty in order to furnish an additional source of prosthetic control.

Patient's Estimation of Advantages

It was of interest to us to determine how the patients felt concerning the advantages of the cineplastic prosthesis. Thirty patients stated that the greatest benefit was improve-

ment in prosthetic control, and fourteen liked best the unilaterality of operation. Ten patients treated by biceps cineplasty stated that the greatest advantage was the control possible when the arm was in difficult positions of function, such as above the head or behind the back. Nine biceps-cineplasty patients appreciated most the lack of need for a shoulder harness, while three others noted what they thought was considerable improvement in sense of finger position and in sense of the pressure applied to the terminal device. Other stated advantages seemed less significant.

A total of eighty-eight patients (82.2 per cent) felt that the cineplastic prosthesis was definitely superior to the conventional type. In the biceps-cineplasty group seventy of the wearers (89.7 per cent) noted this superiority and even among the non-wearers,

TABLE IV

REASONS FOR NON-WEARING OF THE CINEPLASTY PROSTHESIS

Reasons	Total Group (41 Patients)	Biceps Cineplasty (21 Patients)	Pectoral Cineplasty (20 Patients)
Not Related to Hospital Management:			
Prosthesis broken, lost, or destroyed	7	5	2
Does not need prosthesis	6	4	2
Prefers conventional type	2		2
No reason	6	4	2
Total	21 (51.2%)	13 (61.9%)	8 (40.0%)
Related to Hospital Management:			
Irritation of skin in tunnel	6	3	3
Pain in stump	9	2	7
Prosthesis unsatisfactory	3	2	1
Inadequate excursion	2	1	1
Total	20 (48.8%)	8 (38.1%)	12 (60.0%)

thirteen (61.9 per cent) felt that cineplasty has much to offer. In the pectoral-cineplasty group, however, only seventeen (58.6 per cent) thought that cineplasty was superior. Among those who were wearing their prostheses regularly, six (66.7 per cent) expressed this feeling, and among the non-wearers eleven (55.0 per cent) were of this opinion.

Reasons for Not Wearing Cineplastic Prostheses

An analysis of the causes of non-wearing of prostheses was revealing. The results of this analysis are shown in Table IV. It became apparent that the reasons for the non-wearing of prostheses could be divided into (1) those related to the patient's hospital management and (2) those due to reasons beyond our control. Of the forty-one failures, about half (51.2 per cent) could be attributed to factors which had no connection with hospital management. Of the twenty-one failures in the biceps-cineplasty group, 61.9 per cent were due to these uncontrollable factors, whereas in the pectoral-cineplasty group only 40.0 per cent were due to these factors. In the entire group of 107 patients, only 18.7 per cent ceased to wear the prosthesis because of factors related to hospital management. In the biceps-cineplasty group the percentage of failures due to these reasons was only 10.3, but in the pectoral-cineplasty group it was 41.4. The ratio of the failures in the two groups which could be attributed to some theoretically controllable factor in hospital management was roughly 4 to 1. This is further evidence of the suitability of the biceps-cineplasty procedure in comparison with the pectoral-cineplasty procedure.

Eventual Prosthetic Use

We endeavored to determine what eventually happened to those patients who failed to wear their cineplastic prostheses regularly. Did they turn to conventional prostheses or did they give up entirely and depend on their remaining extremity for function? It was found that of the forty-one non-wearers, only twelve (29.3 per cent) had obtained conventional arms (four of the twenty-one non-wearers in the biceps-cineplasty group and eight of the twenty non-wearers in the pectoral-cineplasty group). The reason for this is conjectural. One can theorize that some of the patients did not have a proper desire for any form of prosthesis. This would mean that if the selection of the patients had been better, there would have been more regular wearers of the cineplastic prosthesis. On the other hand, it may be held that the cineplasty procedure should not be done before the patient has been permitted to try a conventional prosthesis. It would seem that, having no experience with the possibilities of conventional fitting, the patients who, for some reason, were unable to use their cineplastic prostheses, became discouraged and felt that other types of fitting would be equally unsuccessful. The failure of non-users to try a conventional prosthesis is certainly an argument against the indiscriminate use of the highly specialized cineplasty procedure in patients who do not have the proper interest, intent, or motivation.

Relation to Dominance of Extremity

It was at first believed that the question of the wearing or non-wearing of a cineplastic prosthesis might have some relation to whether the amputation was on the dominant or subdominant extremity. It was found that in the entire group there were forty-eight patients whose amputations were on the dominant side and that twenty-nine of these (60.4 per cent) were wearers. There were fifty-nine whose amputations were on the subdominant side and thirty-seven of these (62.7 per cent) were wearers. In the biceps-cineplasty group the relationship between the wearers with dominant-side stumps and the wearers with subdominant-side stumps was 70.0 per cent to 76.3 per cent. In the pectoral-cineplasty group, however, only 12.5 per cent of dominant-side amputees were wearers as compared with 38.1 per cent of the subdominant-side amputees. It would seem, therefore, that the success of the biceps-cineplasty procedure will be affected little by the matter of dominance, but that this factor might be of some importance in the pectoral procedure.

Length of Hospitalization

It is obvious that the length of hospitalization as well as various economic factors should be considered in deciding upon the practicality of the cineplasty operation. For institutionalized patients this is probably not as important as it is for patients under private care. We tried to establish a comparison between the length of hospitalization of our cineplasty patients and that of arm amputees treated by conventional methods. In our group of patients the average time between either admission to the hospital or final stump revision and the cineplasty operation was 1.8 months, and the average time between cineplasty and discharge was 6.1 months. The total average hospital time for the cineplasty patient was thus 7.9 months. In comparison with this, the average time between final revision and discharge for the conventionally-fitted arm amputee was 2.5 months, or one-third the hospital time required for the cineplasty amputee. Even if part of the treatment is carried out on an out-patient basis, the comparison still applies to the total length of time before the patient is returned to his own resources. In spite of these incontrovertible facts, however, 93.6 per cent of our patients with biceps-cineplasty and 58.6 per cent of our patients with pectoral cineplasty felt that the added time of hospitalization was justified by the possible benefits that might be derived from the cineplasty procedure.

Surgical Aspects

The surgical technique of biceps and pectoral cineplasty has been fairly well standardized and has been adequately described in detail elsewhere [1–7, 12, 15, 19, 20, 22–24, 28, 30]. While occasional variations in technique were made in this series, the standard unilateral skin pedicle tube was constructed in most patients, a wire pull-out suture being used for closure of the tube. The dual pedicle tube, which necessitates cutting of muscle fibers, is not considered satisfactory and seems indicated only in exceptional cases in which scarring requires the assurance of blood supply to the tube from both sides. The results in the few patients in whom closure of the skin over the exposed muscle was utilized instead of split-thickness skin coverage demonstrated that there is no advantage in this method, and it is felt that it is rarely advisable. In the early operations the tendon of the muscle used for the tunnel was not cut, but in all of those performed in the last four years of our study this technique, first advocated by Lebsche, was carried out. Another modification was that in all of our later pectoral-cineplasty operations the fibers of the clavicular muscles were severed so that there would be muscle pull in only one direction, resulting in less tendency of the pectoral tunnel to rotate.

The surgical complications occurring in the hospital included slow healing of the tunnel in one biceps-cineplasty patient and in five pectoral-cineplasty patients. Two of these required revision and skin-grafting before healing occurred. In seven patients there was either a neuroma or a healing defect in the stump. Two patients required secondary tenotomy of the biceps tendons, which had become adherent. There was inadequate excursion of the tunnel in one pectoral-cineplasty patient and a painful axillary scar leading to prosthetic difficulties in another.

The surgical complications occurring subsequent to discharge from the hospital and reported by the patients fell into three main groups: (1) breakdown of the skin tunnels, (2) contracture of the openings of the skin tubes, and (3) inadequate muscle excursion. Table V shows the incidence of breakdown of the skin tunnels in the course of prosthetic use.

While there was a history of intermittent skin breakdown in 26.2 per cent, it was severe enough to interfere with the use of the prosthesis in only 5.6 per cent. The incidence of severe breakdown in the biceps-cineplasty group was only 3.8 per cent, in comparison with 10.3 per cent in the pectoral-cineplasty group.

There was some contracture of the opening of the skin tunnel in eighteen patients (16.8 per cent). Eleven of these were in biceps-cineplasty patients and seven were in pectoral-cineplasty patients. Some of these required an adjustment in the size of the tunnel pin, but in no instance was the contracture severe enough to interfere with the use of the prosthesis. In two patients, one from each group, the excursion of the tunnel was inadequate for operation of the terminal device, and the use of the cineplasty prosthesis was discontinued.

Analysis of this study of the surgical aspects of biceps and pectoral cineplasty suggests that while the operation is not technically difficult, it must be meticulously performed. Furthermore, it is apparent that it may be associated with disabling complications even when done by experienced surgeons. Breakdown of the skin tunnel and inadequate muscle excursion will take their toll even when the operative technique is scrupulous and the training of the surgeon is adequate. In the hands of the inexperienced an increased incidence of failure due to surgical complications may be anticipated. While contracture of the tunnel opening was not a significant cause of failure in our group of patients, it is still a theoretical possibility, especially if the operation has been performed by an inexperienced surgeon.

The question of the presence of hair in the tunnels as the cause of skin breakdown in patients treated by pectoral cineplasty was considered, but its importance was not believed to be significant. It is our feeling that pectoral-tunnel breakdowns are probably

more often related to tortional stresses exerted by the cable attachments than they are to follicle infections caused by hair.

Training Aspects

We tried to determine whether the cineplasty amputee felt he had received sufficient indoctrination and training for the proper use of his prosthesis. We were concerned with the possibility that an improper introduction to the cineplasty procedure, to the prosthesis itself, and to the methods of operation of the prosthesis might be factors in subsequent non-use. The majority of the patients were of the opinion that they had received sufficient training. Most of them felt they had been properly briefed preoperatively on what to expect from their prostheses and they were not disappointed. They felt that the mechanical instruction they had received before actual training was begun was sufficient for them to grasp the principles of prosthetic operation. Most of them stated that their training gave them confidence in the use of their prostheses. The ones who were wearing their appliances stated that their family and friends also believed they were using them in a satisfactory manner. An analysis of these replies convinces us that in this particular group the indoctrination and training were adequate and that the failures could not be attributed to shortcomings along these lines.

TABLE V

BREAKDOWN OF SKIN TUNNELS

	No. of Patients
Total group	28
Minor	22
Severe	6
Wearers	12
Non-wearers	16
Biceps-cineplasty group	21
Minor	18
Severe	3
Wearers	12
Non-wearers	9
Pectoral-cineplasty group	7
Minor	4
Severe	3
Wearers	0
Non-wearers	7

The most successful surgical procedure in the most suitable and cooperative amputee will be useless without proper psychological and mechanical introduction to the problem associated with the specialized prosthesis and without subsequent training in its use. Unless such facilities are available to the patient, he will be unable to use his cineplastic appliance even though the operative procedure may be a success. This is an important limitation of the specialized procedure and must be kept in mind when the question of cineplasty is being considered.

Fitting Aspects

Our method of prescribing and fitting cineplasty prostheses for patients with upper-extremity amputations at various levels has been reported elsewhere [28, 29]. In this study an attempt was made to determine the adequacy of the prosthetic components as a factor in the wearing or non-wearing of prostheses. The patients were encouraged to express their opinions concerning the function and durability of the various parts of their pros-

theses. It became apparent that these factors could be divided into seven categories: (1) adequacy of the terminal device, (2) durability of the cosmetic gloves, (3) fit of the socket, (4) comfort and practicality of the harness, (5) efficiency of the cables and connectors, (6) durability of the plastic components, and (7) comfort and fit of the tunnel pin.

Adequacy of the terminal device: Ninety per cent of the wearers in the biceps-cineplasty group and 78 per cent of the wearers in the pectoral-cineplasty group were predominantly or entirely hook users. Of these wearers 55 per cent in the biceps-cineplasty group and 86 per cent in the pectoral-cineplasty group wore the hand at times, principally for cosmetic effect. The non-wearers showed no strong preference for either hook or hand. There was general unanimity of opinion concerning the efficiency of the voluntary-closing hook. With few exceptions, all the patients considered this terminal device satisfactory, whether they were predominantly hand or hook wearers. The lowest rate of approval was among the non-wearers in the pectoral-cineplasty group. Concerning the voluntary-closing hand, there was considerable difference of opinion. Practically 100 per cent of those who were predominantly hand wearers considered this terminal device satisfactory. Thirty-seven per cent of those who were predominantly hook wearers, however, made such comments as "poor", "too heavy", "hand slips", "lighter spring required", or "movement needed in all fingers". An analysis of these findings suggests that the prosthetic hook is a satisfactory device but that the hand requires improvements especially in regard to its weight and ease of operation. It should be pointed out, however, that the patient's choice between hand and hook varies with his occupation and his functional requirements as well as with the efficiency of operation of the particular terminal device.

Durability of cosmetic gloves: Among the fifty-seven wearers with biceps cineplasty and the nine wearers with pectoral cineplasty, 58 per cent reported the need for replacement of their gloves—20 per cent because of tears, 8 per cent because of fading, and 30 per cent because of staining. Eighteen per cent definitely did not require replacement, and 22 per cent made no comment. One patient asked that hair be inserted in the glove for greater realism. It must be acknowledged that the high replacement rate of the cosmetic glove is a factor to be considered in its use and may contribute to the non-wearing of the terminal device. It is also indicative of the need for adequate subsequent prosthetic maintenance if the continued use of the mechanical hand is to be expected.

Fit of the socket: In the biceps-cineplasty group of prosthesis wearers, 67 per cent reported that their sockets were comfortable, 20 per cent found them too loose, and only 6 per cent reported that they were either painful or poorly fitted. Of the non-wearers in this group only 24 per cent reported that their sockets were comfortable, while another 24 per cent reported that they were either painful or poorly fitted. In the pectoral-cineplasty group there was a similar discrepancy of opinion as to socket comfort between wearers and non-wearers. The definite complaint of a painful socket was made by three patients in the non-wearer group, but by none of those who were wearing their prostheses. The available evidence suggests that the fit of the socket may be an important factor affecting the wearing of the prosthesis.

Comfort and practicality of the harness: Among the biceps-cineplasty wearers, 71 per cent found their harnesses comfortable, 9 per cent found them too loose or generally bothersome, and the remainder made no comment. Of the pectoral-cineplasty wearers, 56 per cent found the harnesses comfortable. Those who reported difficulty with their harnesses were about equally divided in their complaints, which included "too loose", "too tight", "leather rubs in the armpit", and "desire wider straps". Among the non-wearers only two patients found their harnesses to be painful. From the replies of the patients nothing could be inferred as to any definite connection between the comfort and practicality of the harness and the wearing or non-wearing of the prosthesis.

Efficiency of the cables and connectors: Forty-six per cent of the patients reported

breaking of the cables, 10 per cent noted cable rusting, and 2 per cent experienced difficulty with connectors. These complaints were experienced equally by all the patients, both wearers and non-wearers. These factors may be important in the wearing of a prosthesis; adequate maintenance facilities must be provided if use is to be continued.

Durability of plastic components: The vast majority of the cineplasty patients reported complete satisfaction with the durability and wear of the plastic components of their prostheses. It is our feeling that no fault in these components influenced the eventual wearing or non-wearing of a prosthesis.

Comfort and fit of the tunnel pin: Among the cineplastic-prosthesis wearers the great majority found no fault with the fit of the tunnel pin. About 10 per cent noted various difficulties, including "pin slides out", "pin too loose", "pin too long", "pin painful when tunnel is sweating", "pin too tight", and "connectors don't stay fastened". Among the non-wearers, 25 per cent complained that their tunnel pins were definitely painful. This represents one of the real weaknesses of the cineplasty procedure and is an important factor in subsequent wearing of the prosthesis. The pain may be the result of inadequate surgery, unfavorable condition of the skin, or improper fitting of the tunnel pin. The fact that none of the wearers complained of pain but that it was noted by 25 per cent of the non-wearers seems to be of considerable significance.

Conclusion: As regards prosthetic fitting, it would seem that imperfect fitting of the socket and difficulty with the tunnel pin contribute prominently to the non-wearing of a prosthesis. As regards the mechanical components, the need for lighter hands with lower activating spring forces, more durable cosmetic gloves, and stronger cables seems apparent. Too early fitting of the stump may be responsible for socket looseness and subsequent disuse of the prosthesis. Throughout the study we continually found evidence that without provision for proper prosthetic maintenance, repair, and replacement after the patient leaves the hospital, there is little hope for continued use of a cineplastic prosthesis, even though the surgical circumstances, the training facilities, the prosthetic fitting, and the patient's motivation and ability are all that can be desired. All cineplasty amputees must be aware of this and should be told where they can obtain parts and repairs as the need arises. If these maintenance problems cannot be solved by local limb fitters or by the use of Veterans Administration facilities, the patient should have the privilege of returning his cineplasty prosthesis for repair to the place where he received it. If the distances are great, this may well be too difficult, which is one possible reason for the patient not wearing the appliance. This factor should be considered in the initial decision as to cineplasty, and it has been the reason for our refusal to perform the operation on some foreign patients who had little hope of obtaining proper prosthetic maintenance.

ADVANTAGES OF CINEPLASTY

From our experience with this group of patients as well as with others not included in this report, we have been able to crystallize the apparent advantages of the cineplasty procedure. If these advantages do not appear sufficient to justify the procedure for any specified patient, the increased surgery, training, period of hospitalization, and economic burden may well be cancelling considerations.

Biceps cineplasty in the below-the-elbow amputee provides the great advantage of elimination of the shoulder harness with resultant increased comfort. The procedure also affords the amputee an enlarged sphere of action so that he can use his prosthesis above his head or behind his back, areas which are generally inaccessible with conventional harnessing. The patient can use each arm independently, an advantage which is greatly appreciated by mechanics and other skilled workers. Finally, biceps cineplasty in the below-the-elbow amputee appears to provide, at least to some extent, an increased kinesthetic sense in the use of his terminal device. This means an improved sense of the

position of and pressure applied to his artificial hook or hand. This kinesthetic advantage, sometimes called "graded prehension", varies with individual patients.

In the above-the-elbow amputee whose stump is long enough to accommodate a biceps prosthesis, the advantages are not so immediately apparent. Since elbow function must be replaced, it is necessary to fit the patient with a shoulder harness which will produce flexion of the prosthetic forearm, operate the elbow lock, and help stabilize the prosthesis on the stump. The patient is thus harness-restricted and his sphere of action is more limited than is that in the below-the-elbow amputee. However, since he may operate the terminal device independently of forearm flexion (separation of controls), he is not as restricted in his sphere of action as is the conventionally fitted above-the-elbow amputee. A decided advantage of the biceps-cineplasty fitting for the above-the-elbow amputee is the ability of the patient to perform repetitive tasks with the forearm at a given angle of flexion without having to move the terminal device away from the sphere of activity. Furthermore, biceps cineplasty increases considerably the degree of forearm flexion at which the activation of the terminal device can be satisfactorily accomplished. There will not be complete independence of the arms in patients with amputations at this level because of the necessity for the stabilizing shoulder harness.

Pectoral cineplasty offers little in comparison with biceps cineplasty. Here the amount of harnessing required is comparable to or even greater than that used with the conventional type of prosthesis. There is no increase in the sphere of action and no significant improvement in kinesthetic sense over the conventional type of control. The only great advantage of pectoral cineplasty is that it provides an additional source of prosthetic control in patients with very short arm stumps who require this added control for the successful operation of any prosthesis. It may eliminate the need for a nudge or perineal elbow-lock mechanism, which is usually awkward and often mechanically unsuccessful. For these reasons pectoral cineplasty may fill an urgent need, especially in patients with bilateral shoulder disarticulation in whom the successful fitting of any prosthesis is a serious problem. If, in the future, this problem can be solved mechanically, the advantages of pectoral cineplasty will be even less significant than they are today.

PROPER APPLICATIONS AND LIMITATIONS OF CINEPLASTY

It is apparent from our experience that while cineplasty is attractive to surgeons and patients and offers a number of advantages, there are certain factors which make its usefulness limited. The requirements for optimum conditions regarding surgery, training, prosthetic fitting, and subsequent maintenance have already been discussed. There still remain the important physical, psychological, vocational, and economic factors which may well make the difference between success and failure. The muscle to be used must be of sufficient strength to provide adequate tunnel excursion. The condition of the skin must be appropriate for the fabrication of the tunnel, and the stump should be free of neuromata and tender scars. It would be folly to expect a satisfactory result if the joints to be moved in using the prosthesis do not have adequate ranges of motion.

The selection of patients from the point of view of psychological and vocational suitability is of great importance. The amputee usually presents an emotional problem which must be carefully handled by the surgeon, physiatrist, and technical assistants. To convince him that an additional and cosmetically deforming operative procedure may be advisable is to risk the danger of further emotional conflict. The eagerness of the patient for this additional procedure after its advantages have been explained is an element in the decision concerning cineplasty. The ability of the patient to grasp the full meaning of his disability, his willingness to cooperate, his intelligence, and his apparent intention to improve his capabilities will be important factors. The age of the patient will also be a consideration. From our experience with children, it is our feeling that cineplasty is not indicated before the age of twelve or thirteen years. It is possible to

perform cineplasty in younger children for the tunnel will undoubtedly grow with the patient. Psychologically, however, these individuals seem unable to take advantage of their cineplasty mechanism and often discard the prosthesis, whereas they can easily be taught to use conventional types. The child with bilateral shoulder disarticulation may be an exception. It is also questionable whether young children should be given the added deformities of skin tunnels which may be objectionable to them in later life. Most women object seriously to muscle tunnels, and we feel that the operation is not appropriate for them.

The previous education of the amputee, the type of work he expects to do, and his vocational maturity will all be factors in the selection of patients. As a general rule, cineplasty will be appropriate for individuals who do skilled labor and will be contraindicated when heavy work is required. It will be used to better advantage by the intelligent, willing, and cooperative patient, and by those who have reached a stage of relative vocational maturity. If an amputee has been well established in a certain job, it is possible to make a more adequate evaluation of his physical needs which will assist the clinic team in deciding for or against cineplasty. Because of his disability such a patient may be required to change his vocation, and the use of maximum rehabilitation techniques, including cineplasty, may permit a painless transition to an occupation similar to his former one.

The patient who has not yet decided on a specific vocation and is uncertain as to his job capabilities offers a more difficult problem, and vocational testing and training may be necessary before the decision for cineplasty is made. An untrained individual can often be more readily channelled into the group which may be benefited by cineplasty.

There will always be some individuals who will hesitate in deciding on the procedure or some for whom there is uncertainty as to its suitability. For these reasons we firmly believe that every amputee should have a minimal six-week trial use of a conventionally fitted prosthesis before the decision for cineplasty is made. This gives the amputee time to determine whether he is satisfied with the conventional type or still desires the advantages of cineplasty. It may help him decide whether the extra surgery, time, and economic burden are worth while. It will also aid the surgeon in deciding whether the patient will be a suitable candidate for the operation.

In the selection of patients for cineplasty the problem of associated disabilities must be considered. For the bilateral upper-extremity amputee, the advisability of a single cineplastic tunnel is well established. If a tunnel is made in each arm, however, the problem of getting the prosthesis on and connecting the tunnel pin is almost insurmountable and usually it has been necessary to construct an additional device to accomplish this. It would seem, in such cases, that a cineplasty on one side with a conventional fitting on the other would be the satisfactory solution. There is a difference of opinion concerning the advisability of cineplasty in blind persons with bilateral amputations. When one extremity can be used for probing, with retention of tactile sensation, a conventional fitting of the opposite extremity will usually permit satisfactory grasp and control. In those individuals who have a stump of adequate length with normal sensation which can be used to assist the conventionally fitted opposite extremity, cineplasty will offer little advantage and is probably not advisable.

A final consideration which is not of primary importance but which is certainly a factor is the economic aspect. The patient must decide whether he is financially able to pay the increased costs of the cineplasty procedure and whether he can spend the extra time away from his normal gainful occupation. There will also be a considerably longer time before he receives his prosthesis. This may be of lesser importance to the institutionalized patient, but it is a grave problem to the patient under private care. Industrial firms and insurance carriers will require further education along these lines in order to understand the long-term advantages of cineplasty for selected patients.

SPECIFIC INDICATIONS FOR CINEPLASTY

On the basis of the information gained by this study and the experiences of others in the field, we have designated the specific indications for biceps and pectoral cineplasty. We feel that no patient should be considered for any type of cineplasty unless he fulfills the basic requirements already pointed out. The careful selection of the patient for whom cineplasty is contemplated is probably the most important factor, provided the surgical, training, and fitting facilities are satisfactory. The minimal six-week trial period of a conventionally fitted prosthesis will eliminate many borderline cases, especially those patients who are not quite certain whether they want cineplasty.

Biceps cineplasty in the below-the-elbow amputee who meets the basic requirements provides outstanding advantages. It is, therefore, our feeling that all such amputees should have the privilege of this procedure if possible. For the long above-the-elbow amputee, however, the advantages of biceps cineplasty are not nearly so great and the use of the procedure in this type of individual remains controversial. Our opinion is that it is appropriate for selected patients who require an increased sphere of action and the best available kinesthetic sensibility.

These same clear-cut advantages are not obtained by pectoral cineplasty, at least not in the present stage of surgical and prosthetic development. We feel that this procedure, in direct contrast with the biceps procedure, should be utilized only in patients with exceptional fitting problems, such as the patient with bilateral shoulder disarticulation who is unable to use any prosthesis without an additional source of control. In such individuals the pectoral tunnel can be used for the terminal device, thus freeing other body movement for manipulation of the forearm lift and the elbow lock. Some surgeons have utilized the pectoral tunnel for the elbow lock alone. We feel that this is not a preferred arrangement, since the amount of force supplied by a good tunnel is far in excess of that required to operate an elbow lock. We believe that pectoral cineplasty should not be performed specifically for elbow-lock control.

RECOMMENDATIONS CONCERNING ROUTINE PROCEDURE FOR CINEPLASTY CANDIDATES

We cannot overstress the need for cooperation among the members of the clinic team in the selection of candidates for cineplasty, in the actual performance of the procedure, and in the postoperative rehabilitation of the patient [18]. It is our practice to interview all arm amputees on the question of cineplasty while the amputation stump is being properly conditioned for the fitting of a conventional prosthesis. Following either primary definitive amputation or secondary stump revision, these patients are treated by intensive stump shrinking, exercises to build up thoracic and stump muscles, and measures to mobilize the remaining joints [27]. Shrinkage is started immediately after operation, but the exercises are deferred for two weeks until complete wound healing has occurred. The patient then attends a joint conference consisting of surgeon, physiatrist, and prosthetist. The problem of cineplasty is thoroughly presented to him and the various factors which have been brought out in this paper are carefully considered from the physical, psychological, vocational, and economic points of view. The patient has probably seen others in his ward using their cineplastic controls, but if he has not, it is advisable to have a patient demonstrate the advantages of the procedure and answer questions from the amputee's point of view. If it is the consensus of the staff that cineplasty will be desirable, this is so stated, but the final decision rests with the amputee. If the staff feels that it is inadvisable, then any desire of the amputee to have it will be overruled. In any event, when stump conditioning has been completed, a conventional fitting is made and the patient learns to operate his prosthesis by means of shoulder control.

Occupational and physical therapy should be instituted as soon as wound healing is

complete, and the patient may be assisted in either retaining dominance of the amputated extremity or beginning the process of converting dominance. Before the patient is given his conventional prosthesis, the recognized check-out procedure is carried out in order to assure proper fitting and to avoid the development of faulty prosthetic habits. The amputee is first made aware of the mechanics of the prosthesis and is instructed in its control. When proficiency in this phase has been achieved, training in its use is begun. During the period of instruction—if cineplasty seems desirable—the patient is not only introduced to the conventional device but is constantly reminded of the advantages of cineplasty. The training procedure used for the cineplastic prosthesis differs little from that used for the conventional device, so that the six-week trial period is not wasted time. It is essential that the patient develop maximum skill in prehension if the full benefits of the cineplasty procedure are later to be achieved. It is also important that the patient is not permitted unlimited possession of the prosthesis until it is absolutely certain he is using all components in the most efficient manner. Training is often needlessly prolonged because careless and inefficient methods of use, which may have been developed under improper guidance, must be overcome.

At the end of the six-week trial period the patient is usually well able to control his conventional prosthesis and has definite ideas concerning cineplasty. He is then interviewed again by the clinic team and the cineplasty procedure is either decided upon or discarded. The patient still requires expert professional guidance in the decision, but in many instances a patient who has been interested in cineplasty has decided against it after a fair trial with the conventional prosthesis. In no case do we attempt to persuade a patient to accept cineplasty, nor are we ever swayed by the patient's wishes for cineplasty if we feel it is inadvisable.

Patients selected for cineplasty are operated upon by the standard surgical procedure. A single pedicle skin tube is constructed, a wire pull-out suture being used. The severed tendon is imbricated, and a split-thickness skin graft is applied [30]. The tubes are usually three and one-quarter by three and one-half inches in size and are rotated through 90 degrees in order to avoid subsequent pressure by the pin at the suture line. After the operation, a petrolatum gauze roll is placed in the tunnel, a compression bandage is applied, and a splint is kept on for two weeks. At the end of the two-week period the petrolatum gauze roll is gently removed and is replaced by a similar roll for an additional week. Three weeks after operation, the wire suture is removed and, if the wound has completely healed, the gauze roll is replaced by the tunnel pin which will be used in the prosthesis. If the inside of the tunnel is still incompletely healed, a dry gauze roll is used until healing is complete.

It should be emphasized that no tunnel exercises are encouraged until complete healing of the tunnel and of the area about the skin graft has occurred. This rarely takes place before four weeks and often it is not complete until six weeks. While shoulder and elbow movements are encouraged at the end of three weeks, the use of the tunnel before complete healing has taken place is detrimental to the eventual result and produces prolonged morbidity with unnecessary delay in the use of the prosthesis. The longer interval before starting tunnel exercises has not been responsible in any instance for adherence of the tendon in the scar. We have not noticed any clinical evidence that the development of maximum muscle force and excursion is retarded when exercises are deferred until the wound has completely healed.

Following removal of the gauze roll three or four weeks after the operation, gentle daily cleansing of the skin tunnel is done, and occasionally ultraviolet radiation is used within the tunnel to promote healing. After complete healing of the skin, the exercises which were instituted prior to cineplasty are resumed and the tunnel pin is attached to weights for progressive-resistance exercise after the method of DeLorme and Watkins. In biceps tunnels, dissociation of tunnel action from flexion of the forearm stump is

necessary at first in order to obtain smooth operation of the prosthetic unit. Exercises to build up the power and excursion of the muscle are then instituted.

When tunnel movement is adequate for function of the prosthesis, the cineplastic-controlled appliance is fitted to the patient. After the harnessing has been accomplished and before the patient is given complete possession of his new prosthesis, the check-out procedure is again carried out. It is surprising how rapidly the patient learns to operate the cineplastic controls after his previous training with conventional harnessing. In most cases in which skin healing is complete and muscle excursion is adequate, only a few additional days of training will be required. In the patients treated by biceps cineplasty, little adjustment in fit of the prosthesis is necessary, and the original sockets are utilized in practically all instances. Caution is indicated concerning too early fitting of amputee stumps, because subsequent shrinkage may necessitate additional smaller sockets. This complicates the patient's training, and the loss of much valuable time may be avoided if patience is exercised by the surgeon in obtaining complete shrinkage of the stump before the primary fitting.

CINEPLASTY IN PROSTHETICS RESEARCH

It is our opinion that cineplasty, especially the biceps type, is a procedure of considerable usefulness in selected patients and that further development of this method should be encouraged. However, it must be pointed out that the procedure is a highly specialized one and that its importance in the total picture of the rehabilitation of the amputee should not be overemphasized. It is apparent that further studies in muscle mechanics and physiology will be helpful in the future evaluation of the usefulness of the cineplasty procedure, and it is also true that future improvements in the fitting, materials, and mechanics of prosthetic devices may widen the indications for cineplasty. Nevertheless, we wish to make it clear that in the present stage of development, sixty years after the introduction of the procedure, we are dealing with an operation which is applicable to only a relatively small percentage of arm amputees. The bulk of future prosthetics research would be more properly directed to problems which deal with the great majority of amputees who will not be eligible for cineplasty.

SUMMARY

1. An end-result study of seventy-eight biceps cineplasties and twenty-nine pectoral cineplasties reveals that 61.7 per cent of the patients were wearing their prostheses at the end of a year or more. In the biceps-cineplasty group the percentage was 73.1 and in the pectoral-cineplasty group it was 31.0.

2. Cineplasty should be performed only at established amputation centers where all the members of the clinic team can participate in the proper selection of patients, where there are surgeons familiar with the operative procedure, where training supervision by experienced physiatrists is available, and where the fitting can be done by prosthetists who understand the peculiar problems of the cineplasty amputee. There must also be provision for subsequent specialized prosthetic maintenance.

3. Cineplasty operations should be limited to carefully selected patients. The local condition of the stump, the desire and motivation of the patient for the procedure, and the functional requirements of the patient should all be taken into consideration.

4. When these requirements are met, the advantages of the biceps-cineplasty procedure to the below-the-elbow amputee are sufficiently great so that the operation should be offered to him. The advantages of biceps cineplasty to the long above-the-elbow amputee are not so apparent, and the usefulness of this procedure remains controversial.

5. At present pectoral cineplasty has limited usefulness. It should be employed only in patients with such exceptional conditions as bilateral shoulder disarticulation; in such a patient an additional source of prosthetic control is urgently required.

6. Cineplasty is not advisable in amputee patients prior to adolescence, and it is not usually cosmetically acceptable to women.

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DISCUSSION

Dr. Rufus H. Alldredge, New Orleans, Louisiana: This important report illustrates how far we have come in the field of upper-extremity amputation since World War II. In 1946, we still did not even know

whether cineplasty had a place in this field. Since then we have learned that it does have a place and that it is here to stay. The Walter Reed Report, which is one of the few end-result studies based on a significantly large number of cases, confirms the importance of cineplasty. In studying this report, as well as others of its kind, it should be kept in mind that there is always a percentage of unilateral amputees who will not continually wear or use a prosthesis of any kind. We are not certain what the incidence is, but it has been variously estimated to be from 10 to 50 per cent. At the present time, because of improved artificial limbs and more adequate training, it may be safely estimated that only 10 to 20 per cent of the arm-amputee population will not regularly use a prosthesis of any type.

The authors' report shows that at the end of a year only 61.7 per cent of the cineplasty patients in their series were still regularly using the prosthesis, while 82.9 per cent of a series of conventionally fitted patients treated at the same time were still using the prosthesis. It is practically certain that if the authors were now to apply their increased knowledge of cineplasty to a similar series of patients, they would be able to obtain as good results by cineplasty as are obtained by conventional prosthetic fitting. It is seriously doubted that they would do as many cineplasties as they have done in the past. The total number of cineplasties would be smaller, therefore, but the percentage of excellent results would increase in proportion. Bilateral amputees are quite a different problem and will, in 100 per cent of the cases (except for the blind), utilize to the fullest possible extent any type of prosthesis given them.

The cineplasty operation should be done only by those who have special interest and experience and should be used only when facilities are available for the necessary after-care, including proper prosthetic fitting and training. Generally, it has been done too often, on too many patients, with too little understanding on the part of those responsible for the result.

Cineplasty is most useful when the biceps muscle is used, as Col. Brav and his associates have already pointed out. It is most appropriate for patients with a short below-the-elbow stump and in the majority of these patients, it gives a better result than does any other method. Pectoral cineplasty is less useful, but it is helpful in some difficult and severe cases, as the authors have pointed out. In our series we found the use of biceps cineplasty in patients with above-the-elbow stumps of more value than did the authors. These patients will, I am sure, derive more benefit from cineplasty than is generally believed.

I do not agree with the authors on one point. I cannot understand the reason or necessity for routine fitting of all patients with a conventional prosthesis before the decision for cineplasty is made. I feel that, in most cases, this results in unnecessary time and expense. Of course, for institutionalized patients this would not make a great difference, but for others it would. For some patients, especially those with above-the-elbow amputations, it may be difficult and confusing to change from one type of prosthesis to the other.

Dr. Charles O. Bechtol, New Haven, Connecticut: We would like to present a brief review of cineplasty in civilian practice to supplement the authors' review of cineplasty in military practice. In our experience, biceps cineplasty, especially in patients with below-the-elbow amputations, is by far the most satisfactory. The biceps muscle is adequate, and a standard prosthesis may be obtained in almost any limb shop in the country. It should be noted that the Army Prosthetic Research Laboratory type of voluntary closing hook or hand is most suitable for the cineplastic prosthesis, for it allows the amputee to use his kinesthetic sense in determining how far he has closed his terminal device and also provides the means for graded prehension, so that the amputee can grasp an object with either a light force or a heavy force. In civilian practice it is always wise to have the amputee fitted with a shoulder-harness type of prosthesis first so that general amputee training can be carried out before the complication of cineplasty is added. Finally, it should be emphasized that cineplasty should be done only by a surgeon with a thorough knowledge of physiology and of prosthetic requirements.

Lt. Col. Fletcher (closing): In the early days of cineplasty it was thought that an extra source of control was mandatory to assure the practical operation of the prosthesis. In patients with very short above-the-elbow stumps it was found that the forces created by the pectoral cineplasty for operation of the terminal device were so powerful that a counter-torque mechanism was needed to prevent critical loss of control power between the pectoral center and the terminal device.

As progress has been made, we have been able to develop automatic controls which eliminate the necessity for additional sources of power in the unilateral above-the-elbow amputation prosthesis and in the shoulder-disarticulation prosthesis. By the development of mechanisms which automatically cause the elbow to lock and to become stabilized, it has been possible to provide satisfactory arm movement without a cineplasty tunnel in patients in whom, previously, an additional source of control would have been necessary.

It is our hope that in the future most of the problems related to prosthetic design will be solved, so that prostheses will become increasingly efficient and will permit the full rehabilitation of the amputee, restoring him to his fair competitive place in society.

Discoid Lateral Meniscus of the Knee Joint

Nature, Mechanism, and Operative Treatment

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From the Department of Anatomy, College of Physicians and Surgeons, Columbia University, New York

The incidence of so-called "discoid" lateral meniscus of the knee joint is not great. In one of the largest series, a series of 1300 meniscectomies reported by Smillie, only twenty-nine congenital discoid menisci were found. In other reported series, the incidence has not been very different [3]. The author has had occasion to operate upon six knees presenting this affiiction.

Observations on anatomical material dissected at the College by first-year medical students and by the author during the past ten years has disclosed few cases of discoid menisci. Only one cadaver was found with lateral discoid menisci in both knees. The rare incidence of the discoid abnormality in this laboratory series is difficult to explain.

The etiology of the discoid meniscus and the mechanism of the clicking sound which it produces have been only partially explained. The majority of orthopaedic surgeons believe that the discoid abnormality is caused by arrest of the development of the meniscus in the embryo [2, 6, 10]. In accordance with this view, it was decided to make a study of menisci removed from knee joints at surgery in order that the different types might be determined and classified.

In an important article on this subject, Smillie stated, "[the fact] that the menisci exist as cartilaginous discs at an early stage of development, and that the congenital discoid meniscus is due to occasional persistence of the fetal state, is not in question". Smillie also said that three different main types have been encountered: the primitive, intermediate, and infantile. This point of view obviously implies the existence of menisci of discoid form in the embryo, these menisci gradually changing shape until the adult form is obtained.

One of the most persistent symptoms of the discoid meniscus is a loud clicking sound which is produced by flexion and extension of the knee joint. The explanations thus far given for this abnormality do not make it clear why the clicking occurs, why a discoid meniscus is frequently present in both knees of the same individual, and why it is seldom accompanied by pain and difficulty in function, unless connected with an injury.

It has been found that the removal of a discoid meniscus is more difficult than the removal of a non-discoid lateral meniscus.

To answer the questions mentioned above, several simultaneous studies have been made.

Embryology of the Meniscus [1, 7, 8]

An embryological study was made to determine at what stage of the development of the human foetus the lateral meniscus assumes a discoid form. Material from fetuses in all stages of development was examined. The material was obtained from several hospitals and from the Institute of Embryology in Baltimore (Carnegie Institute). Some material was studied in the Department of Anatomy of the College. The results of this study were reported in detail at the Annual Convention of the Alumni Association of the Hospital for Joint Diseases in October 1955.

The embryological study revealed quite definitely that at no time in the development of the human foetus does the lateral or medial meniscus assume a discoid form. The

intermediate zone between the femur and tibia which appears very early in the development of the knee of the embryo is called the intermediate disc. This disc does not break up into separate medial and lateral discs, however, but develops early into two semilunar menisci. Even during the first few days of development, the aspect of the meniscus is similar to that in the adult.

Since it was clear that during fetal development there is no discoid meniscus, an attempt was made to find an animal in which there is a meniscus over the lateral aspect of the tibia in the form of a disc.

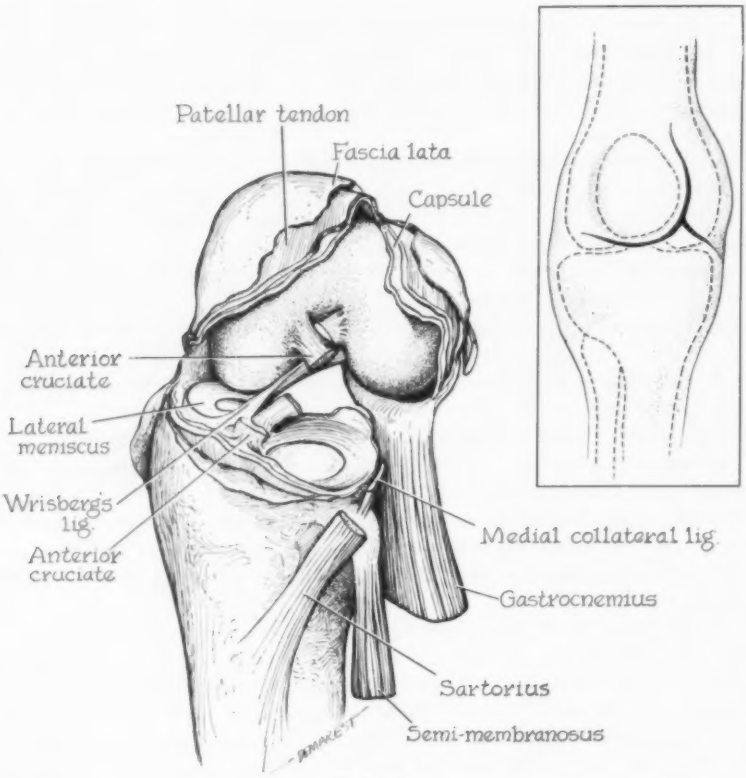

FIG. 1-A

Right knee of a chimpanzee, opened and dissected, as shown in the insert. Only the structures which are important for this demonstration are shown. The femur was drawn in flexion and the tibia in abduction in order to show the knee from the medial side. The medial meniscus is semilunar in form; the lateral meniscus is circular. The meniscofemoral or Wrisberg's ligament is actually continuous with the posterior horn, but in this view this insertion is hidden by a fold of the synovial membrane.

COMPARATIVE ANATOMY OF THE MENISCUS [9, 11]

An extensive comparative-anatomy study was made of the knee joints of various animals. The investigation of the comparative anatomy of the menisci was only a part of this study. The other important structures about the human knee were also investigated; the findings of this study will be reported separately *.

Not many comparative studies of the structures in the knee joint have been made to determine the function of normal and abnormal knees from the clinical viewpoint.

* A report on the comparative anatomy of the iliotibial band was presented at the Sixty-eighth Annual Convention of the American Association of Anatomists in Philadelphia in April 1955.

The anatomist is seldom concerned with the clinical aspects of structures, while the clinician has only rare occasions to make comparative-anatomy studies. An isolated statement has been found that the lizard is the only possessor of a discoid meniscus [4]. From a critical review of the literature, however, it appears that no one has claimed to have actually observed a discoid meniscus in any animal.

For purposes of this study, the knees of a young gorilla, three chimpanzees, one orangoutang, one gibbon, two rhesus monkeys, one lemur, one bear, one pig, one sheep, one bullfrog, one iguana, one alligator, several birds, one lion, and several cats and dogs were dissected by the author. In this series, not a single animal was found with a meniscus,

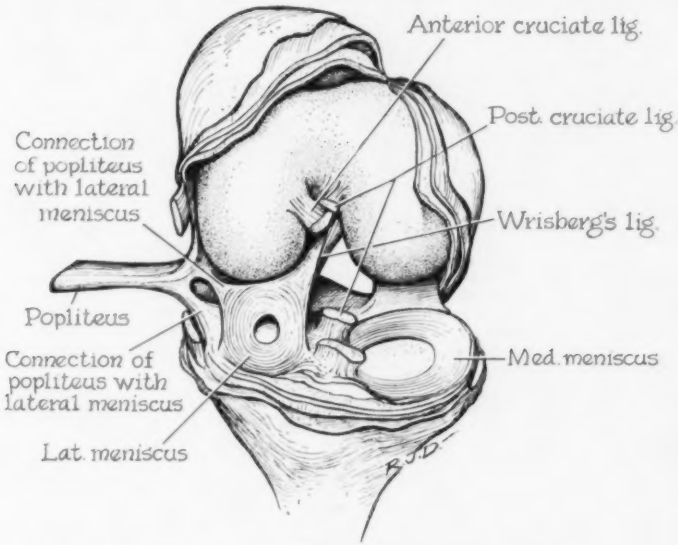

FIG. 1-B

The same knee with both the femur and tibia in flexion. The relationship of the meniscofemoral ligament to the lateral meniscus is shown more explicitly. The posterior part of the lateral meniscus is completely detached from the lateral tibial spine, and the only visible attachments are those to the meniscofemoral ligament, coronoid ligament, and popliteus tendon. The firm posterior attachment of the medial meniscus is clearly demonstrated.

either lateral or medial, which resembled a disc, although some of them did have circular menisci.

This experimental series definitely established that the existence of a discoid meniscus in any animal, including the lizard, is highly improbable. On the other hand, it confirmed the fact that in all animals, with the exception of man, the lateral meniscus of the knee has only one insertion, an anterior insertion into the tibial plateau, and that there is no attachment to the tibia posteriorly. It has been known that in most anthropoids the posterior horn of the lateral meniscus is not attached to the tibia (posterior to the lateral intercondylar tubercle), but that the anterior horn is attached to the tibia (the anterior part of the lateral intercondylar tubercle), as it is in man. Instead of the posterior horn or the posterior part of the lateral meniscus being attached to the tibia, it is fixed to the medial femoral condyle by a ligament known as the ligament of Wrisberg or the meniscofemoral ligament. This ligament connects the lateral meniscus to the lateral aspect of the medial condyle near the posterior margin, behind the posterior cruciate ligament. It is frequently double, running posteriorly from the posterior end of the meniscus and anteriorly to the posterior cruciate ligament. When traction is applied to the

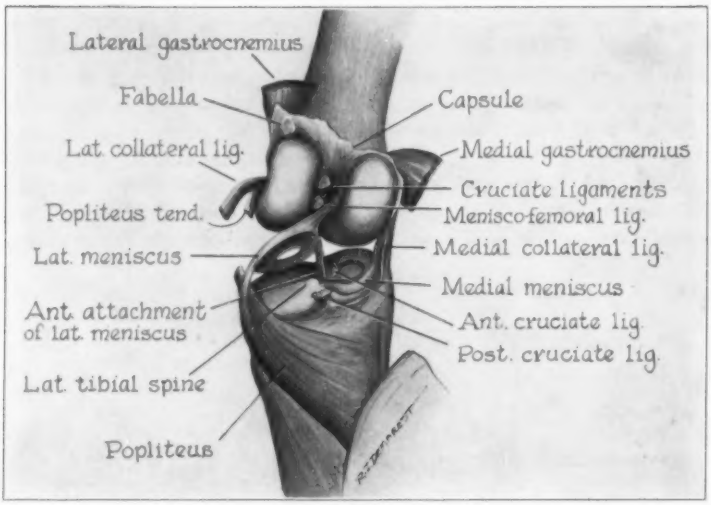

FIG. 2

Left knee of a gibbon dissected posteriorly. The joint is in a position of extension. The circular lateral meniscus is shown being pulled toward the femur by the meniscofemoral ligament, there being no posterior attachment of the meniscus. The lateral meniscus has an anterior attachment and also a strong connection with the popliteus. The medial meniscus cannot be elevated from the tibia, being firmly attached to the tibia anteriorly and posteriorly.

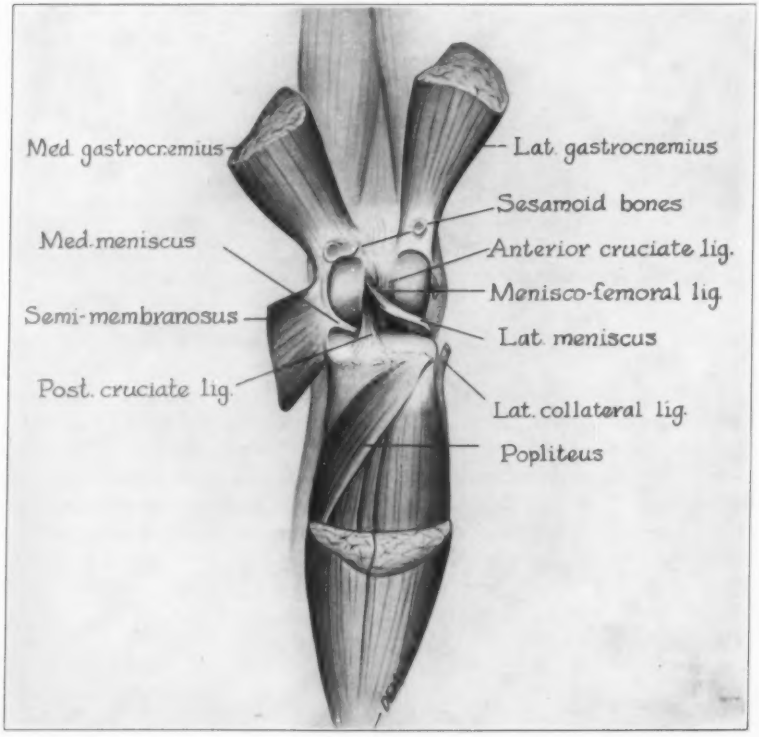

FIG. 3

Fig. 3: The posterior aspect of the right knee of a cat. The lateral meniscus is completely unattached posteriorly to the tibial plateau and is elevated from the surface of the tibia by the pull of the meniscofemoral ligament.

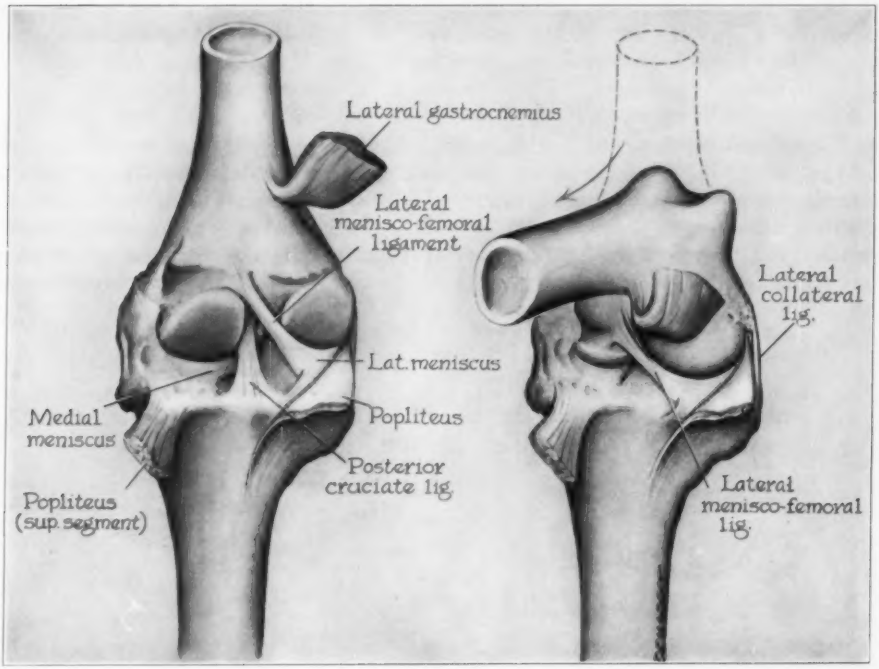

FIG. 4

The posterior aspect of the right knee of a sheep.

Left. When the knee is extended, the lateral meniscus is pulled up toward the femur while the medial meniscus remains attached to the tibia. The attachments of the lateral meniscus to the meniscofemoral and coronoid ligaments are shown.

Right. When the knee is flexed, the posterior part of the lateral meniscus is in a more posterior position and rests on the tibial plateau. The position of the medial meniscus is not much changed. The wide angle through which the femoral condyles move in lateral rotation is demonstrated. The meniscofemoral ligament descends to the base of the posterior cruciate ligament from behind.

meniscofemoral ligament in the dissected knee of any anthropoid but man, the lateral meniscus, except for the anterior end, is elevated from the tibial plateau. In all the anthropoids observed in this experiment, the lateral meniscus was almost completely circular but was never discoid (Figs. 1-A, 1-B, and 2). The same disposition was found in other animals (Fig. 3).

On the basis of the embryological and anatomical studies, the author established that neither in human fetuses nor in the animals examined (representing mammals, birds, amphibians, and reptiles) is there a meniscus which has the form of a disc.

THE LATERAL MENISCUS AND THE LIGAMENT OF WRISBERG

It is well known [12] that, normally, in the human knee, the lateral meniscus is attached to the tibial surface in two places, on the anterior and posterior aspects of the lateral intercondylar tubercle. It is also known that the lateral meniscus is attached to the femur by a ligament known as the meniscofemoral ligament. In human anatomy this structure is known as the ligament of Wrisberg; it runs behind the posterior cruciate ligament, starting laterally at the posterior horn of the lateral meniscus and crossing the posterior cruciate ligament obliquely before reaching its point of insertion on the

lateral surface of the medial condyle. In the French, German, and Russian literature, this ligament is known as Robert's ligament.

An anterior branch of Wrisberg's ligament is usually also found. This branch, known as Humphry's ligament, runs anteriorly to the anterior surface of the posterior cruciate ligament, into which it blends.

MECHANISM OF MENISCAL MOTION

The mechanism of normal meniscal motion has been determined quite well by many investigators[2, 5, 9, 14]. The knee is not a simple hinge joint but is a complicated joint in which three types of motion occur: rolling, gliding, and rotation. The menisci follow the motions of the condyles. A simplified description would be that they move forward during extension and backward during flexion (Fig. 5-A). The lateral meniscus moves more freely than the medial. The axis of rotation of the knee is nearer the latter. It is known

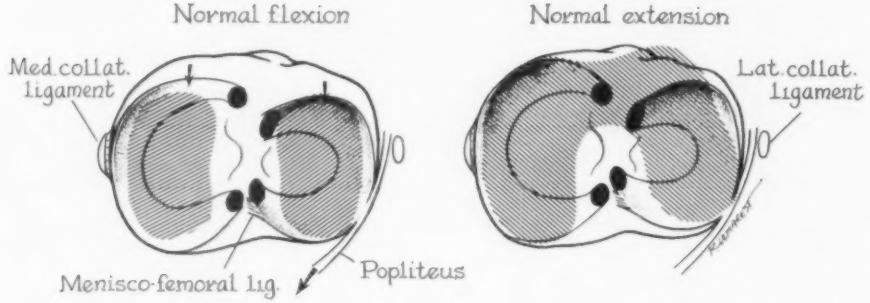

FIG. 5-A

Figs. 5-A and 5-B: These illustrations demonstrate the mechanism of meniscal movement in a normal human right knee and, for purposes of comparison, in a knee with a discoid meniscus.

Fig. 5-A: Normal knee. Flexion is accompanied by posterior displacement of the lateral meniscus which is pulled backward by the contraction of the popliteus. The popliteus is responsible for the flexion and medial rotation of the tibia or for the lateral rotation of the femur, which amounts to the same thing. In extension the condyles of the femur rotate medially and both menisci move forward, the lateral more than the medial, for the latter is almost static. In this drawing the striped area represents the projection of the condyles on the tibia and the solid black oval spots represent the anterior and posterior insertions of the anterior and posterior horns of the menisci; there are four such attachments in the normal knee.

that during complete extension of the knee joint, the femur executes a final medial rotatory motion. When the knee begins to flex, the popliteus (the function of which is similar to that of the pronator teres at the elbow) flexes the knee, simultaneously rotating the tibia medially and the femur laterally. Thus, the lateral meniscus, in following the motion of the lateral femoral condyle, not only recedes posteriorly but rotates laterally.

The popliteus is frequently attached to the posterior portion of the lateral meniscus. This attachment extends into the posterior capsule, a structure which is firmly connected both to the meniscofemoral ligament and to the posterior cruciate ligament. Contraction of the popliteus produces traction of the meniscus in a downward and lateral direction. At the same time, however, the tendon of this muscle glides into a groove on the lateral meniscus and, thus, in normal knees, appears to restrict lateral displacement of the meniscus.

Man is the only animal who maintains constant and complete extension of the knee during his activities and in his normal stance. In other animals, the predominate functional position is flexion. Stability of the knee in this position rather than control of the knee when it is in a position of complete extension is required in these animals, and for this reason, the lateral meniscus must have more freedom of rotatory motion.

This is made possible by the absence of an attachment of the posterior horn to the tibia and by the presence of the meniscofemoral ligament.

MECHANISM OF MOTION OF MENISCI IN ANIMALS

Examination of the dissected knee joint of any animal demonstrates clearly what occurs in this joint during flexion and extension. For purposes of demonstration, a knee joint of a sheep was dissected and is illustrated (Fig. 4). The knee of this animal has a much wider degree of rotation than does the knee of man. In extension (Fig. 4, left view), the lateral meniscus is prevented from moving too far forward by the meniscofemoral ligament. In flexion (Fig. 4, right view), the lateral rotation of the femur is exaggerated, the meniscofemoral ligament is relaxed, and excessive backward movement of the lateral meniscus is prevented by the attachment of the anterior horn to the anterior end of the intercondylar tubercle.

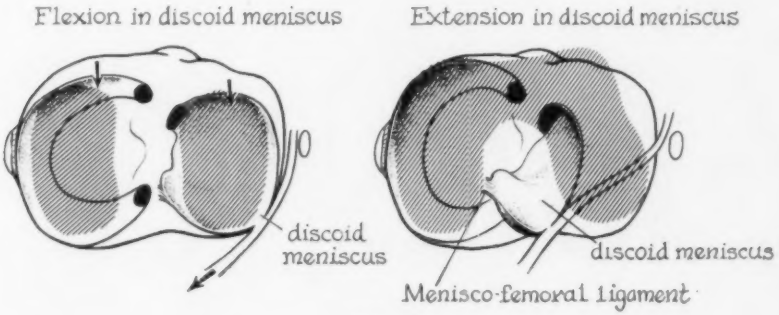

FIG. 5-B

Knee with discoid lateral meniscus. In this illustration there are only three black spots representing insertions, for the posterior horn of the lateral meniscus has no posterior attachment. In flexion the popliteus tendon pulls the lateral meniscus backward, as it does in the normal knee. In extension, however, the popliteus tendon is relaxed and the meniscofemoral ligament, being too short to permit the natural forward motion of the lateral meniscus, pulls the meniscus in a medioposterior direction. As the posterolateral margin of the meniscus passes the condyle, a characteristic click is produced. When the motion of the knee changes from extension to flexion and the meniscus returns to its position on the lateral tibial plateau, a second click is produced. In this drawing, the popliteus tendon is shown, for reasons of emphasis, as being pulled into the joint. In reality, however, the popliteus and the coronary ligament apparently glide more or less deeply under the lateral condyle and lateral tibial plateau.

The excellent control of the knee joint possessed by such animals as the mountain goat, the lion, and the bear is the result of the absence of the posterior attachment of the lateral meniscus. Because there is no posterior attachment, the meniscus has a much wider excursion and is, therefore, better able to adapt itself to the movements of the femoral condyle during rotation of the tibia. The excursion of the meniscus is controlled by the meniscofemoral ligament and by the action of the popliteus.

There are, of course, other factors which account for the difference in function of the animal knee joint. In many mammals, although not in the anthropoids, the extensor digitorum longus does not originate from the tibia but instead originates from the lateral femoral condyle in front of the popliteus tendon. The femoral origin of the extensor digitorum longus in animals crosses the knee joint at a right angle to the articular line, in front of and parallel to the lateral collateral ligament, thus constituting an additional stabilizing factor; this muscle is wider than the lateral collateral ligament. In all animals but man the extensor digitorum longus, the coronary ligament, and the popliteus tendon contribute to the anchorage of the lateral meniscus, for which there is no posterior tibial attachment.

Examination of specimens of discoid lateral menisci removed at operation by several orthopaedic surgeons including the author have permitted the formation of several conclusions leading to an understanding of this clinical entity.

OBSERVATIONS ON DISCOID MENISCI AT OPERATION

It was found that in all the patients observed at operation, the discoid lateral meniscus had no posterior attachment to the tibial plateau. It was also found that the discoid meniscus was attached, as are the menisci of all other animals, to the lateral aspect of the medial condyle of the femur by a strong meniscofemoral ligament, which did not permit the lateral meniscus to move completely forward during full extension of the knee.

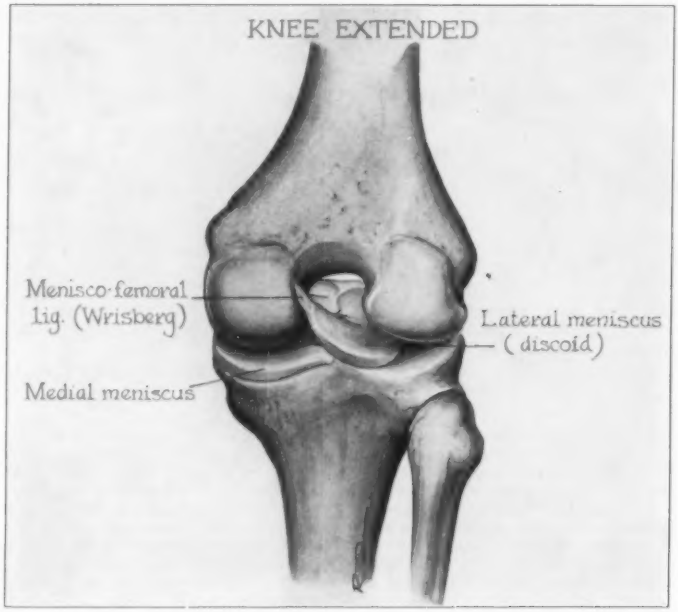

FIG. 6

Posterior aspect of a human right knee showing the posteromedial displacement of the discoid lateral meniscus which has no posterior tibial attachment.

When a knee with a discoid meniscus was opened through an anterior incision, it was observed that the lateral meniscus completely disappeared into the cavity of the knee joint upon extension of the joint. When the knee was flexed, the meniscus came nearer the anterior edge of the tibia but was still barely visible. The motion of flexion and extension was accompanied by a loud clicking sound. A posterior incision, either between the biceps femoris tendon and the iliotibial band or between the biceps femoris and the lateral head of the gastrocnemius with the capsule opened, showed the exact mechanism of the lesion (Figs. 5-B and 6). At each extension of the knee joint, the lateral meniscus, unattached to the tibia but held by the short and stout meniscofemoral ligament, dislocated into the intercondylar space. At each flexion, the lateral meniscus, being released from the pull of the short meniscofemoral ligament, was pulled laterally by the coronary ligament and the tendon of the popliteus. The mediolateral movement was responsible for the clicking sound. The movement of the meniscus into the posterior part of the intercondylar space was effected by the meniscofemoral ligament, which was too short to permit the meniscus, not fixed posteriorly to the tibia, to remain in place under the

lateral femoral condyle. During flexion the normal pull of the contracting popliteus and the coronary ligaments permitted the return of the meniscus to its usual position.

DIFFICULTIES IN SURGICAL REMOVAL OF DISCOID MENISCI

Removal of the discoid meniscus through an anterior incision involves difficulties, as has been experienced by many surgeons. These difficulties are the result of several factors: because of the solid form of this meniscus, it is not possible to grasp the inner edge with a hook in order to tense it; it is sometimes very difficult to find the meniscus when the knee is extended because the meniscus tends to disappear into the intercondylar space; an attempt to free the posterior horn from the tibia through an anterior incision is,

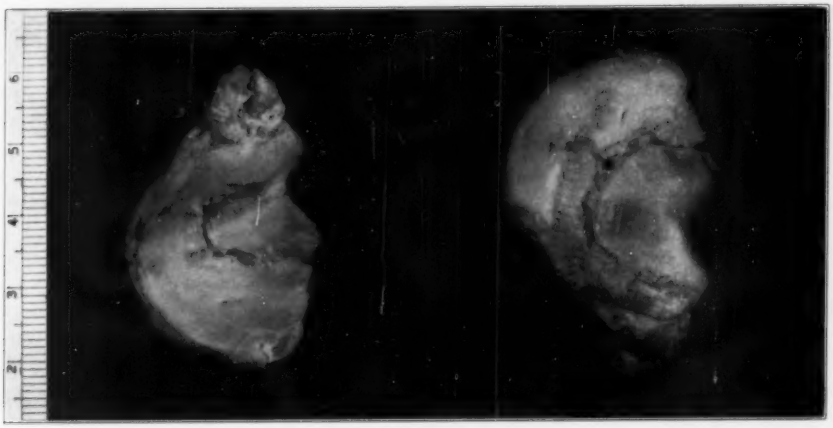

FIG. 7

A "semilunar" meniscus with a "discoid" central portion. (Courtesy of H. Jaffe, Hospital for Joint Diseases.)

of course, bound to fail, since there is no such attachment! When the actual anatomy of the affliction is not suspected, it is not easy to divide the meniscofemoral ligament through an anterior incision.

PATHOGENESIS OF DISCOID MENISCI

The observations of the author led to several conclusions. Apparently certain rare individuals are born with the lateral knee meniscus unattached to the posterior aspect of the tibial plateau, a condition which is normal in other animals. In these individuals the lateral meniscus is held in place by the meniscofemoral ligament, which is too short to accommodate itself to the normal movements of the human knee.

Although, in these individuals, the lateral meniscus doubtless has a circular or semicircular form at birth, its constant mediolateral motion in the growing child produces secondary thickening, transforming this initially normal meniscus into a thick fibrocartilaginous mass which assumes a solid irregular form.

Pathological examination of the specimens reveals considerable infiltration by polymorphonuclear cells and thickening of the cartilaginous fibers. At times, the original semilunar form is preserved, but an abnormal central portion within the semilunar cartilage is observed. In these cases the central portion is apparently formed later, possibly as a result of abnormal movements of the meniscus (Fig. 7).

A case of discoid lateral meniscus in both knees is presented as an illustration.

The patient, G. M., a nine-year-old girl, was operated upon at the Hospital for Joint Diseases. Through a small transverse skin incision, the posterolateral aspect of the left knee joint was approached. A longi-

tudinal incision was made between the lateral collateral ligament and the biceps femoris, the popliteus tendon was identified, and the meniscus was located. Another incision was then made over the anterolateral aspect of the knee, between the patellar ligament and the iliotibial band. The knee was flexed and extended in order to demonstrate the movement of the meniscus, and it was found that the meniscus moved posteriorly and medially on extension and returned to its normal position on flexion. The "jumping" of the meniscus into the posterior medial compartment and then back to the lateral tibial plateau produced a double click. No posterior attachment of the lateral meniscus to the tibial plateau was found, but a thick Wrisberg's ligament was found between the meniscus and the medial femoral condyle. The division of the Wrisberg's ligament permitted easy removal of the meniscus through the anterior incision.

RECOMMENDED PROCEDURE FOR REMOVAL OF A DISCOID MENISCUS

The removal of the discoid meniscus should be performed through two incisions: one between the biceps femoris and the lateral collateral ligament and the other between the patellar ligament and the iliotibial band. The principal part of the operation consists in the division of the Wrisberg's ligament to free the meniscus from behind. In very difficult cases, one should place the incision behind the biceps tendon, and, if the proper precautions are taken, one should not hesitate to divide the belly of the lateral gastrocnemius. Once the ligament of Wrisberg is divided, it is simple to separate the meniscus from the popliteus tendon, coronary ligament, and lateral collateral ligament.

It is useful to remember that Wrisberg's ligament is relaxed during flexion of the knee and that the posterior cruciate ligament is tense during flexion and extension. The posterior cruciate ligament, which is almost vertical along the posterior mid-line, is anterior to Wrisberg's ligament. Wrisberg's ligament, running from the lateral side of the knee toward the medial femoral condyle, forms a triangle with the posterior cruciate ligament, the apex of this triangle being near the femoral condyle and the base being at the tibial edge. It is further useful to remember that the ligament of Wrisberg is located only about one centimeter anterior to the popliteal artery, and that dividing it through a blind anterior incision may occasionally result in injury to this artery.

SUMMARY AND CONCLUSIONS

The clinical entity known as "discoid lateral meniscus" was investigated in order to determine its etiology and to explain the mechanism of the click which is frequently observed during flexion and extension of the knee joint. Inasmuch as treatment consists in removal of the discoid meniscus, an attempt was also made to find a more direct method of removal which would be more consistent with the surgical anatomy of this condition.

In a recently reported embryological study of the menisci [8], the author established that in no stage of development, from the earliest phase to birth, does the lateral meniscus appear in the form of a disc.

In a series of comparative-anatomy dissections, the author found that none of the animals available to him, representing mammals, birds, amphibians, and reptiles, had a lateral or medial meniscus resembling a disc.

Observations made at operation showed that in individuals with discoid minisci there is no attachment of the posterior horn to the tibial plateau. Instead of this attachment, there is a continuous Wrisberg's ligament (meniscofemoral ligament) which forms a link between the posterior horn of the meniscus and the medial condyle of the femur. This is similar to the normal arrangement observed in all animals except man.

On the basis of these findings, it was concluded that patients with discoid minisci represent individuals who are born with a normal lateral meniscus, as far as form is concerned, but with an anatomical variation which consists in the posterior horn of the lateral meniscus not being attached to the tibial plateau. In these individuals, as in all animals but man, the meniscofemoral ligament joins the meniscus to the medial condyle of the femur. This anatomical variation does not permit the normal limitation of the

movements of the lateral meniscus which is required by the normal range of motion of the human knee joint.

The discoid form develops gradually after birth and is the result of abnormal motion of the lateral meniscus. The hypertrophied meniscus actually varies in shape but has been fancifully called "discoid".

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The Carpal-Bridge View

A Position for the Roentgenographic Diagnosis of Abnormalities in the Dorsum of the Wrist

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The purpose of this article is to describe a roentgenographic position for the study of the dorsum of the wrist. The postero-anterior, anteroposterior, oblique, postero-anterior in ulnar deviation, and carpal-tunnel views [1] all obscure the area dorsal to the carpal bones. The lateral view of the wrist suffices only to identify lesions in this region, but it fails to provide any information about localization. The carpal-bridge view, as we have named it, offers specific anatomical localization of lesions in the posterior portion

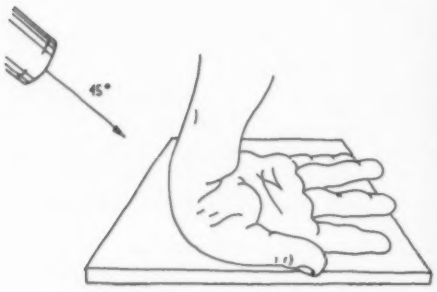

Fig. 1

Fig. 2

Fig. 1: Details of the position. The palm lies face upward, and the beam is aimed at a 45-degree angle, entering the wrist two inches above the table top. A cardboard cassette is used.

Fig. 2: The carpal-bridge view. The soft tissues of the dorsum of the wrist are clearly demonstrated. The triangular, lunate, and navicular form an unbroken arch or bridge.

of the wrist and is of special value therefore in the management of foreign bodies or injuries in this region. We have chosen the name "carpal-bridge view" in order to indicate that it is the precise opposite of the carpal-tunnel view which delineates the palmar soft tissues and the undersurface of the bones of the wrist. The carpal-bridge view shows the volar soft tissues and the superior surface of the bones comprising the carpal arch.

TECHNIQUE

The patient is seated. The arm of the wrist to be examined is perpendicular to the body and the forearm is perpendicular to the table. The hand lies palm upward directly on the cardboard cassette. The patient thus forms a triple right angle; the arm forms a right angle with the body, the forearm forms a right angle with the arm, and the hand forms a right angle with the forearm.

This position is easily assumed by the patient and is simple for the technician to remember. The central ray of the roentgen beam is adjusted at an angle of 45 degrees with the table top and enters the wrist two inches above the table top (Fig. 1). The exposure factors used for any average wrist are: 100 milliampere, one and one-half seconds, fifty kilovolts, thirty-six inch target-film distance, with a cardboard cassette and a cone.

FIG. 3-A

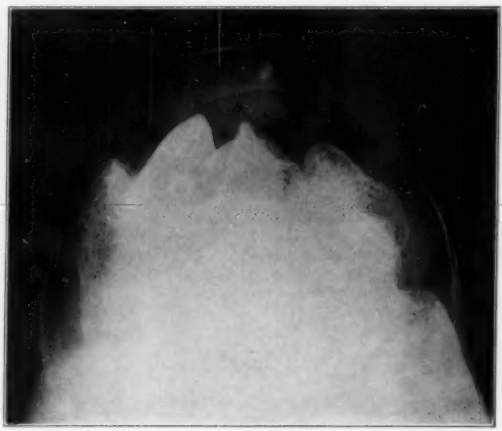

FIG. 3-B

Figs. 3-A and 3-B: Lateral view of the wrist in a patient with a faintly radiopaque foreign body in the dorsum of the wrist. The shadow of the foreign body is only vaguely outlined in the lateral view. It is strikingly demonstrated "on end" in the carpal-bridge view and is seen to lie just superficial to the lunate bone.

ROENTGEN ANATOMY

The roentgenogram produced by the carpal-bridge view is demonstrated in Figure 2. The proximal row of carpal bones and the soft tissues superficial to the carpal bones are clearly demonstrated. The navicular is seen with its long diameter "laid out", while the dorsal portion of the lunate fits snugly between the navicular and the triangular. The triangular itself projects as a triangular density. Superimposition of both the radius and the ulna on the palmar aspect of this arch is readily identified, and the capitate stands out as a large oval bone overlying the inferior margin of the navicular and lunate.

APPLICATION

The carpal-bridge view is not indicated in the routine roentgenographic examination of the wrist. It is mainly of value in abnormalities and symptoms relating to the dorsum of the wrist. The carpal-bridge view would seem to be valuable in the following conditions:

1. *Lunate dislocation:* Dislocation of the lunate bone is generally palmar and is best demonstrated in the lateral view in which the lunate is seen misaligned with the radial concavity and rotated forward. In the carpal-bridge view, straightening or reversal of the normal navicular-lunate-triangular arch, with sagging of the lunate, will be demonstrated. This special view will also assess adequacy of reduction.

2. *Fracture of the navicular:* The navicular is most often fractured through its waist. Hair-line fractures are not infrequent and may be missed. The average fracture of the navicular is best studied with standard views. When the diagnosis is uncertain, the carpal-bridge technique supplies an additional view of the navicular bone through its long axis.

3. *Calcifications in the dorsum of the wrist:* The exact location of tendon calcifications in the dorsal portion (usually in an extensor tendon) may be greatly clarified by the use of the carpal-bridge view. At times, faint calcific flecks may be apparent only in this view.

In the following two conditions the carpal-bridge view is the position of choice for the study of abnormalities:

4. *Foreign body in the dorsum of the wrist:* The traumatic introduction of a foreign body into the dorsum of the wrist occurs frequently. Pieces of graphite from pencils, fragments of glass, and similar objects of low roentgenographic density may be present

FIG. 4-A

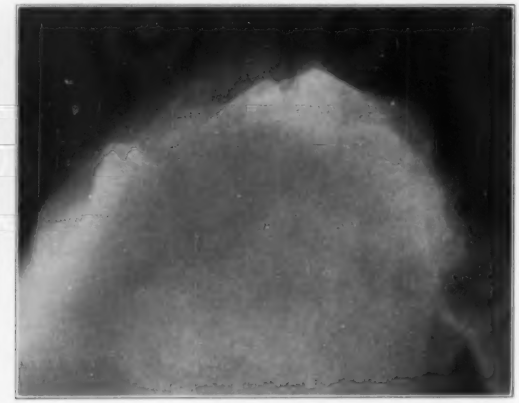

FIG. 4-B

Figs. 4-A and 4-B: Lateral and carpal-bridge views of the wrist in a patient who sustained a fracture of the triangular. The fragments can be seen in the lateral projection, but only the carpal-bridge view clearly demonstrates that the triangular is the bone which has been fractured.

but are often overlooked in routine roentgenographic examinations. When these opacities are seen in the standard examination, they are identified in the lateral view in the soft tissues superficial to the carpal bones. In Figures 3-A and 3-B, we see a lateral view of the wrist in which a piece of graphite from a pencil has been introduced into the soft tissues of the dorsum. This object cannot be identified with any certainty because of its poor roentgenographic density. Examination in the carpal-bridge position clearly defines the foreign body in cross section, with apparent potentiation of the degree of opacification.

The precise localization of a foreign body seen in the lateral view is greatly aided by the carpal-bridge position and removal is facilitated.

5. *Fractures of the dorsum of the wrist:* Small chip fractures of the dorsal aspects of the carpal bones may be detected in the lateral view of the wrist. They are usually not identifiable on the postero-anterior or oblique views, and the precise origin of the fracture is not clear. Roentgenography in the carpal-bridge position may provide striking evidence of the exact fracture site.

The following case history illustrates such a point:

A. B., a white male, forty-two years old, fell on his outstretched hand, with resultant pain and swelling of the dorsum of the left hand. The standard roentgenograms of the left wrist, made elsewhere, were reported as normal. Three weeks later, because of persistent symptoms, the patient was referred to this Hospital for a repeat roentgenographic examination of the involved wrist. Standard postero-anterior, lateral, oblique, and postero-anterior ulnar deviation films of the wrist were made; a fracture of the triangular was suspected but not definitely diagnosed in the lateral view (Figs. 4-A and 4-B).

The patient was returned for a roentgenogram of the wrist in the carpal-bridge position. This view conclusively demonstrated the fracture of the triangular.

CONCLUSION

1. A roentgenographic position, called the carpal-bridge view, is introduced for the diagnosis of abnormalities in the dorsum of the wrist.

2. The value of this position in the diagnosis of lunate dislocation, navicular fracture, foreign body in the dorsum, fracture of the triangular, and tendinitis calcarea is briefly described.

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Medullary Fixation of Forearm Fractures*

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The benefits and advantages of medullary fixation are not as apparent in the treatment of forearm fractures as they are in the treatment of femoral fractures. This conclusion is based on a study of 338 patients with 555 fractures, the data having been accumulated from seventeen sources. Most of the members of the group participating in this study had participated in the previous similar study on the femur and, therefore, were thoroughly acquainted with the principles of medullary fixation †.

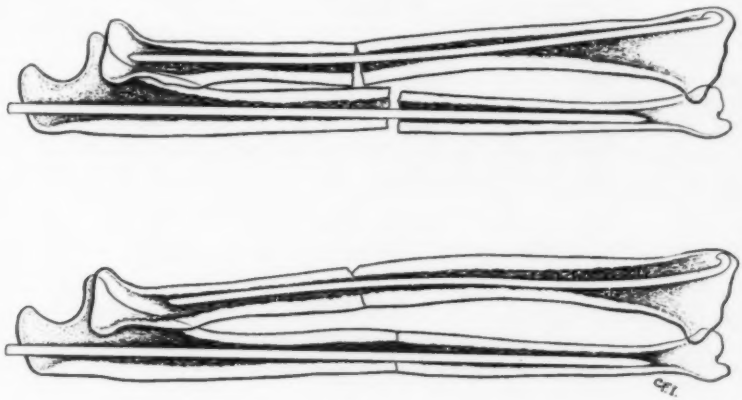

FIG. 1

When medullary pins are used in both bones, fixation of the radius must be sufficiently stable to prevent collapse of the radial arch; otherwise, there will be a relative elongation of the radius with distraction of the ulnar fracture, and non-union may result in either or both bones.

CASE MATERIAL

The distribution of the fractures was as follows: fifty-three fractures in fifty-three patients involved the radius alone, eighty-seven fractures in eighty-five patients involved the ulna alone, and 415 fractures in 200 patients involved both bones (206 fractures of the radius and 209 fractures of the ulna).

Fifty-one per cent of the patients were twenty to forty years of age, 24 per cent were forty to sixty, and 6 per cent were over sixty. The remainder (19 per cent) were less than twenty, but since they were in their late teens, this series can still be considered an adult series. Medullary fixation is not an appropriate treatment for fractures in children.

Approximately three-fifths of the fractures involved the middle third of the shaft,

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† This report has been partially supported by the Research and Development Division, Office of the Surgeon General, Department of the Army. The participants were: Dr. Rufus Alldredge, Dr. Carl E. Badgley, Dr. Edwin F. Cave, Dr. Howard L. Cherry, Dr. Benjamin Fowler, Dr. Oscar P. Hampton, Jr., Dr. J. Vernon Luck, Dr. H. L. McLaughlin, Dr. Harry Morris, Dr. Vernon L. Nickel, Dr. Frederick vom Saal, Dr. Hugh Smith, Dr. Harold Sofield, Dr. Ralph Soto-Hall, and Dr. J. E. M. Thomson. The Brooks Army Hospital and the Walter Reed Army Hospital also participated.

the remainder being distributed equally between the proximal portion of the distal third and the distal portion of the proximal third. Fractures involving the proximal fifth or distal fifth of the bones were eliminated.

This group of fractures presented an unusual challenge, as is apparent from the following approximate figures: one-third of the fractures were compound, one-fifth had remained ununited for over three months, and one-half were comminuted or segmental (Table I); furthermore, one-fourth of the patients had associated fractures in the same extremity (Table II), two-fifths had not received nailing until after fifteen days (Table III), and one-sixth had associated damage to one or more of the major nerve trunks

TABLE I

TYPE OF FRACTURE

Bone Fractured	Type of Fracture: Oblique Transverse (No.)	Oblique Transverse Spiral (Per cent)	Comminuted-Segmental (No.)	Comminuted-Segmental (Per cent)	Fractures Analyzed (No.)	Fractures Analyzed (Per cent)	Not Recorded	Total No. of Fractures
Radius only	30	61	19	39	49	100	4	53
Both bones								
Radius	96	51	91	49	187	100	19	206
Ulna	89	47	101	53	190	100	19	209
Ulna only	37	45	46	55	83	100	4	87
Total	252	50	257	50	509	100	46	555

TABLE II

INCIDENCE OF ASSOCIATED FRACTURES

Bone Fractured	Clavicle, Shoulder, Humerus	Wrist	Elbow	Others	None	Total
Radius only	3 (6%)	1 (2%)	1 (2%)	9 (17%)	39 (74%)	53
Both bones	17 (8%)	7 (4%)	15 (8%)	31 (16%)	130 (65%)	200
Ulna only	1 (1%)	2 (2%)	38 (45%)	12 (14%)	32 (38%)	85
Total	21 (6%)	10 (3%)	54 (16%)	52 (15%)	201 (59%)	338

TABLE III

DURATION OF FRACTURE PRIOR TO FIXATION

Time in Weeks	No. of Patients	Per cent
0–2	202	60
2–13	74	22
13–26	16	5
Over 26	45	13
Unrecorded	1	0
Total	338	100

(Table IV). These facts should be taken into consideration in the interpretation of the end results.

PROCEDURE

The principal type of medullary fixation was the Rush pin (174 fractures), but other types were also included for purposes of comparison (Kirschner wires, ninety-seven fractures; Steinmann pins, 129 fractures; Künschner V nails, thirty-nine fractures; and Lottes nails, twelve fractures). These devices were used in a total of 451 fractures, 176 being used to treat 179 fractures of the radius and 262 being used to treat 272 fractures of the ulna. In ninety-eight patients with 209 fractures involving both bones, a medullary pin was placed in both the radius and ulna. In the other 102 patients with fractures of both bones, one bone was fixed with a medullary pin, while the other (104 fractures) was fixed either by a plate, onlay graft, or wire loop (thirty-three instances) or by the closed method (seventy-one instances). Records showing the degree of stability present immediately following the operation were available for 488 of the 555 fractures. These records showed that in 336 (69 per cent) stability was good, in 101 (21 per cent) it was fair, and in fifty-one (10 per cent) it was poor. For 530 of the 555 fractures records of the degree of apposition immediately following the operation were available. According to these records, apposition was good in 447 (84 per cent), fair in seventy-five (14 per cent), and poor in eight (2 per cent). Often fixation which appeared to be good at the time of surgery was found to be only fair or poor when it was subjected to the dynamic forces of the muscles. Furthermore, changes in position of the bones could not be prevented by means of external fixation if the medullary fixation was inefficient or inadequate.

TABLE IV

NERVE INJURIES

Nerve Injured	No. of Patients	Per cent
Radial	31	9
Ulnar	10	3
Median	4	1
Mixed	8	2
None	285	84
Total	338	99

TABLE V

DURATION OF MEDULLARY FIXATION

Time in Weeks	No. of Patients		Per cent
Under 8	13		12
8 to 17	23		20
17 to 26	25		22
Over 26	51		46
Total number of patients analyzed	112		100
In situ or unrecorded		226	
Total number of patients		338	

Thirty-two patients treated early in this series were permitted immediate active motion. The remainder were immobilized for a mean period of ten weeks. It is the consensus of the group that casts or splints are a necessary supplement to internal fixation. As a rule, both internal and external fixation were maintained until there was definite

TABLE VI

DURATION OF EXTERNAL FIXATION

Time in Weeks	No. of Patients		Per cent
None	32		12
0 to 6	50		18
6 to 13	90		33
13 to 26	59		21
Over 26	44		16
Total number of patients analyzed	275		100
Unrecorded		63	
Total number of patients		338	

TABLE VII

TIME OF UNION (DETERMINED ROENTGENOGRAPHICALLY)

Time in Weeks	No. of Fractures		Per cent
Under 8	74		22
8 to 12	47		14
12 to 17	144		44
17 to 26	65		20
Total number of fractures analyzed	330		100
Unrecorded		225	
Total number of fractures		555	

TABLE VIII

LENGTH OF POSTOPERATIVE FOLLOW-UP

Time in Months	No. of Patients		Per cent
Under 2	19		6
2 to 4	56		17
4 to 6	65		20
6 to 12	110		34
Over 12	75		23
Total number of patients analyzed	325		100
Unrecorded		13	
Total number of patients		338	

roentgenographic evidence of union (Tables V and VI). Frequently this evidence could not be observed until twenty weeks after operation (Table VII). Failure to establish stability by means of a medullary nail prompted the use of supplementary internal fixation in eighteen fractures (a portion of the total series which was not considered statistically significant). In another 115 fractures, grafts were added (chip grafts in 104 and onlay grafts in eleven).

The anatomy of the ulna lends itself readily to medullary fixation. The canal is relatively straight and uniform and is large enough to hold a pin of adequate strength to maintain alignment. Relatively few technical difficulties are encountered when the pin is inserted in either a retrograde or direct fashion, and exposure of the fracture site is minimal. By either three-point dynamic fixation or by a rigid nail that fills the canal, a stable fixation can usually be achieved.

This is not true of the radius. The normal curve or arch of the radius precludes any possibility of reaming out the entire canal; thus the size of the pin is limited to the size of the narrowest portion of the canal, which is the middle third. Furthermore, the pin must be sufficiently springy or malleable so that it can be inserted into the S-shaped curve of the canal. Bending of both ends of the pin before insertion may be necessary to obtain proper seating and fixation. If a straight stiff pin is used, the radial arch will be lost; and if a small, limber wire is used, the dynamic pull of the muscles will be unopposed and the radius will be displaced toward the ulna. Multiple small wires improve this situation but are still inadequate.

Thus, in fixation of radial fractures, the temper and size of the pin are extremely important. Furthermore, the hole drilled in the bone should follow the contour of the medulla as axially as possible. As compared with the femur, tibia, ulna, metacarpal, or metatarsal, the radius is a difficult bone to fix by means of a medullary pin.

The length of postoperative follow-up in this series is shown in Table VIII.

TABLE IX

RANGE OF MOTION

Bone Fractured	Rating Excellent	Good	Fair	Poor	Patients Analyzed	Total No. of Patients
Radius only	11 (26%)	24 (57%)	7 (17%)	0	42 (100%)	53
Both bones	47 (32%)	72 (49%)	24 (16%)	3 (2%)	146 (99%)	200
Ulna only	34 (55%)	17 (27%)	11 (18%)	0	62 (100%)	85
Total	92 (37%)	113 (45%)	42 (17%)	3 (1%)	250 (100%)	338

RESULTS

Since the period of immobilization in this series was not appreciably shorter than normal, the results as regards motion in the elbow, forearm, wrist, and hand showed no great improvement over those obtained by other techniques (Table IX). Eighty-two per cent of the patients analyzed were considered to have satisfactory functional results, that is, less than 20 degrees of limitation of elbow motion and less than 60 degrees of limitation of pronation and supination, with good function in the hand and wrist. Eighteen per cent had moderate to severe limitation. Eighty-eight patients (26 per cent of the total series) were not available for analysis because of non-union, insufficient convalescence, or inadequate follow-up.

In view of the number of patients who had such complications as open fracture, neurovascular damage, and non-union, these results were creditable although not super-

lative. Only in the group with solitary fractures of the ulna was a substantial number of excellent results obtained (40 per cent).

In the group of 104 patients with open soft-tissue injury (176 fractures) (Table X), there were thirteen known instances of infection (osteomyelitis in nine) and the rate of non-union was 25 per cent. In the group of 234 patients with closed fractures, there were five known instances of infection (osteomyelitis in four) and the rate of non-union was 17 per cent. For compound fractures, the results as to both union and healing were considered better than average. In the total series, records on soft-tissue healing were available for 314 patients. These records show that 287 of the patients (91 per cent) had primary healing, nine (3 per cent) had delayed healing, and eighteen (6 per cent) had infections.

TABLE X

SOFT-TISSUE INJURY

Bone Fractured	Open		Closed		Total	
	(*No. of Patients*)	(*Per cent*)	(*No. of Patients*)	(*Per cent*)	(*No. of Patients*)	(*Per cent*)
Radius only	6	11	47	89	53	100
Both bones	74	37	126	63	200	100
Ulna only	24	28	61	72	85	100
Total	104	31	234	69	338	100

TABLE XI

BONE HEALING WITH RESPECT TO TYPE OF FIXATION

Bone Fractured	Type of Fixation	Union	Non-Union	Fractures Analyzed	Unrecorded	Total No. of Fractures
Radius only	Medullary	36 (72%)	14 (28%)	50	3	53
Ulna only	Medullary	63 (80%)	16 (20%)	79	8	87
Both bones	Both bones medullary	143 (76%)	45 (24%)	188	21	209
Both bones	One bone medullary	85 (86%)	14 (14%)	99	3	102
Subtotal	All bones medullary	327 (79%)	89 (21%)	416	35	451
Both bones	One bone plate, wire loop, or bone graft	24 (75%)	8 (25%)	32	1	33
Both bones	One bone closed method	60 (91%)	6 (9%)	66	5	71
Subtotal	All bones non-medullary	84 (86%)	14 (14%)	98	6	104
Grand total	All methods	411 (80%)	103 (20%)	514	41	555

The medullary pin is perhaps most outstandingly useful in the treatment of severe mangling injuries of the forearm. A pin inserted in the ulna is usually well tolerated by the host for a lengthy period, with the result that alignment and length can be maintained during the healing of massive soft-tissue defects. Non-union may result, but the simple medullary procedure makes subsequent reconstruction and rehabilitation measures easier to perform. Certainly, when infection is a potential or present complication, the medullary nail is better tolerated than are plates or screws which must be placed in a superficial or exposed location. Position and length are maintained far better by medullary fixation than by skeletal traction or by other conservative means.

An analysis of the rate of union, the paramount factor, revealed that there was a high percentage of non-union (Table XI; see also Table VII). At first, this finding would seem to indicate that closed methods or the use of a medullary nail in one bone with closed treatment in the other would be preferable procedures. However, this does not take into account the high incidence of malunion with proportionate decrease in motion and function which is found in patients treated by closed methods. Another possible but erroneous conclusion is that medullary fixation itself is a major cause of non-union. This conclusion is disproved by the fact that if the ninety-five fractures treated by Kirschner wires are eliminated (rate of non-union, 38 per cent), the rate of non-union for the remaining 321 fractures treated by medullary fixation (all other contributing factors being disregarded) is a respectable 14 per cent. This compares favorably with other methods of treatment; in fact, a non-union rate of 14 per cent would seem to be our base line for this consecutive series of forearm fractures treated by open methods. In the group of solitary fractures of the ulna and in the group of fractures of both bones with either one or both bones fixed by medullary pins (excluding cases in which Kirschner wires were used), the rate of non-union was also 14 per cent, the only group with a higher incidence of non-union (26 per cent) being solitary fractures of the radius.

The results of treatment in the twenty-six segmental fractures were considered most satisfactory: position was maintained adequately by a relatively simple maneuver with minimal exposure and the rate of non-union was not excessive, being 23 per cent.

This analysis of the rate of union emphasizes an established principle of medullary fixation, namely, that the fracture fragments must be held in apposition by a nail with sufficient stability to prevent side-to-side, angular, or rotatory motion. It is not a sound principle merely to aim for the middle ground between extreme instability without internal fixation and rigid internal fixation with a rod or plate. In fractures of both bones use of a supple, small medullary pin in the radius may have an adverse effect on the ulnar fracture even if the latter is securely fixed, for with collapse of the radial arch, there is relative elongation of the radius and subsequent distraction of the ulnar fracture. As a consequence, non-union frequently results in both bones (Fig. 1).

Ninety-seven fractures treated by supplementary multiple grafts were available for analysis. Of these fractures twenty-five had failed to unite. This should not be regarded as evidence against the use of grafting, however, for in this group an overwhelming number of unfavorable factors were present: fourteen of the fractures were comminuted or segmental, seven were compound, and sixteen showed established non-union; in fifteen, Kirschner wires had been used, in seventeen, stability and apposition were poor, and in two, osteomyelitic infections had developed. In the series as a whole these same unfavorable factors were frequently associated with non-union, as were also such other factors as premature removal of fixation, associated fractures in the same extremity, excessive soft-tissue damage, and neurovascular injury. In general it may be said that in complicated fractures, particularly those with prolonged non-union, inadequate bone-grafting combined with medullary fixation will not yield a high percentage of good results. In fresh closed fractures or in fractures in which nailing has been delayed but in which unfavorable factors are not predominant, adequate grafting will yield desirable results.

When the duration of the fracture prior to nailing was correlated with the presence of non-union, the following results were found: of 253 fractures treated within fourteen days of injury, fifty (19.7 per cent) showed non-union; of eighty-nine fractures treated fifteen to ninety days after injury, seventeen (19.3 per cent) showed non-union; and of seventy-three fractures treated after three months or more, twenty-two (30.1 per cent) showed non-union. It appears from these statistics that the time of nailing is not important. However, if all compound fractures are eliminated from the group treated within fourteen days, it will be seen that the results in the remaining fractures in this group were considerably better than those in the other two groups. In the patients with established non-union, use of autogenous onlay grafts or, in some instances, of the Phemister technique would have produced better results.

As has been noted, the medullary pin is not always an adequate means of fixation. In this series there were eight bent pins and seven broken pins; furthermore, excessive shortening and angulation occurred in thirty-nine patients, synostosis occurred in six patients, and eight patients showed neurovascular residual disability.

CONCLUSIONS

In the treatment of forearm fractures, the results obtained by medullary fixation are probably neither better nor worse than those obtained by any other single technique. These results are disappointing, however, when compared with those obtained by the same method in the treatment of femoral fractures. The most important contribution of this method to the treatment of forearm fractures is perhaps that it maintains length and alignment with a minimal incidence of infection in the presence of severe soft-tissue injury. In the treatment of solitary or segmental fractures of the ulna, it is an efficient, rapid, and simple procedure. In the treatment of radial fractures, however, the technique is not simple nor is it uniformly efficient. The authors feel that the design of the pins and the technique of their insertion, particularly for the radius, can be improved appreciably.

ADDENDUM

Since this paper was written, 100 radii have been studied with particular reference to the anatomy of the medulla. On the basis of the anatomical data obtained by this study, one of the authors (Sage) has designed a triangular nail of proper malleability with pre-bent curves which closely simulate the normal arc of the medulla. In the small series (twenty patients) in which this nail has been used, the technique of insertion and the efficiency of fixation of the radius have been considerably improved.

DISCUSSION

Dr. G. W. N. Eggers, Galveston, Texas: This survey of 555 fractures of the forearm treated by intramedullary fixation is convincing evidence that a successful treatment of these fractures is far from being realized. The authors' analysis of their series should contribute to an improvement of the results, however, for their conclusions are based on sound judgment and the material they have presented is worthy of close and accurate study.

There are many types of forearm fractures, and probably each person has his own idea how each should be treated. One outstanding factor that I personally have noticed in the treatment of all types of forearm fractures is that supination and pronation should be controlled, that is, the shearing forces exerted on the fracture site should be decreased. A second important factor is that the continuity of the bones in the fracture area should be restored.

Our observations on the control of supination and pronation indicate that there are many ways in which this may be accomplished, the most important being proper application of a cast. In the radius, marked rotation at the fracture site seldom occurs. This bone is free to rotate at both ends but is held in position at the fracture site by the compression of the muscles. Both fragments of the radius are controlled by muscles, the pronator teres and supinator acting on the proximal fragment and the pronator quadratus and brachioradialis acting on the distal fragment. The coordinated action of these muscles results in a decrease in the shearing forces.

Unfortunately, the ulna is fixed by the olecranon and, therefore, is not subjected to the compressive and

(Continued on page 188)

The Management of Congenital Dislocation and Dysplasia of the Hip by Means of a Special Splint *

BY FREDERIC W. ILFELD, M.D., LOS ANGELES, CALIFORNIA

From The Children's Hospital, Los Angeles

The purpose of this paper is to present a dynamic method for the treatment of congenital disease of the hip in children by an abduction splint. In young children, primary reduction may often be obtained with gradual abduction splinting. In older patients, the splint eliminates many months in plaster casts.

The value of gradual abduction of the thighs with a splint has been long recognized [1].

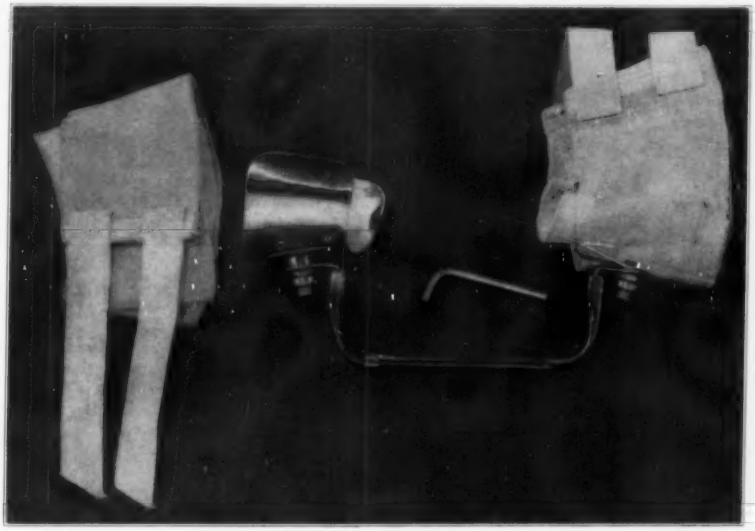

FIG. 1

Two thigh cuffs are fastened to an adjustable bar by universal joints; there is no pelvic band.

Denis Browne, Ponseti, Wu, Frejka, and many others have devised and used effective splints similar to the one used in this study.

THE SPLINT

The splint (Fig. 1) is easily adjusted for abduction and growth, controls rotation of the hip, and has no pelvic band. It consists of two metallic thigh cuffs with washable covers fastened to an adjustable bar by universal joints, similar to those reported by Gibson. The cuffs are locked in place with a hexagonal wrench which the surgeon retains in order to prevent home adjustment. In addition, the thigh bands are connected by a right-angle joint with stops to allow motion through 90 degrees, enabling the patient to sit or to lie down. Shoulder straps (Fig. 2) or an elastic pelvic belt are sometimes needed to hold the

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, February 1, 1956.

FIG. 2

FIG. 3

Fig. 2: The splint with shoulder straps attached; the perineum is left free for easy diaper change.
Fig. 3: Patient is shown walking in the splint

splint in position. The crossbar affords a handle for lifting. The pelvis is free for easy perineal care. Splinting is dynamic, since the patient may kick, sit, crawl, stagger, walk, or run (Fig. 3).

For internal rotation, an adjustable outrigger bar (Fig. 4) is attached to the cross piece and to a metallic cuff on the shin. With the thighs fixed, pressure against the leg by the outrigger bar rotates the hip internally. Such a position still permits crawling and walking (Fig. 5).

RATIONALE

The dislocation of the hip is reduced by gradual abduction of the thighs without force. Kicking and functional use of the legs lessens adductor spasm, allowing slow and gentle abduction. As the thighs are separated by successive adjustments of the splint and by exercises, the hips (Fig. 6) are abducted and rotated externally — the frog-leg position being assumed. The hip and thigh muscles exert a pull directed towards the acetabulum. This pressure and motion is thought to aid in the better seating of the femoral head and in the development of the acetabulum. In younger children, this procedure alone will usually reduce the dislocation or subluxation. The splint, therefore, is the primary method of treatment without hospitalization, anaesthesia, or cast.

When the splint is first applied in the surgeon's office, it is adjusted onto the patient's thighs without force in the position of maximum abduction. For the initial week or two, the splint is worn full time except for removal for bathing. The motion of the legs and the position of abduction lessens adductor spasm and permits adjustment of the brace into further abduction and external rotation at weekly intervals. In infants under one year of age, the dislocation is usually reduced in one to four weeks. Then the patient may be checked monthly.

When there is contracture of the adductor muscles, preliminary abduction traction or adductor tenotomy may be indicated. If reduction is not obtained in one to two months, closed manipulation under anaesthesia or open reduction is indicated. If the hip is stable

FIG. 4

FIG. 5

Fig. 4: With the thigh fixed, outward pressure on the leg internally rotates the hip.

Fig. 5: Patient is shown walking in the splint fitted with a rotator bar.

Fig. 6: Frog-leg position. The hip muscles exert a pull directed toward the acetabulum. The splint is removed daily for rotation exercises in abduction.

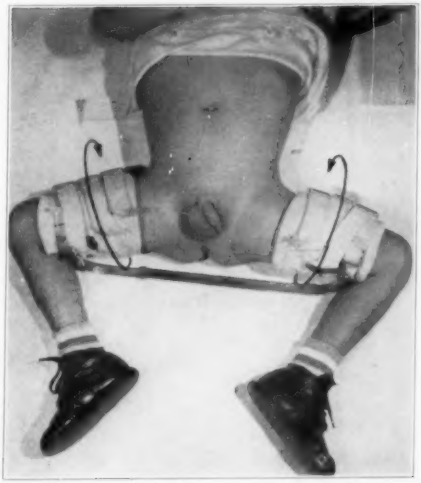

FIG. 6

on closed reduction, the splint may be used and the customary treatment in plaster cast is omitted. In such instances, the splint remains in place for four to six weeks without removal for bathing or exercise. The splint is worn full time for several months. Then night splinting is begun and continued until roentgenograms show adequate development of the femoral head and the acetabulum.

The splint is removed daily for bathing and rotation-abduction exercises from the beginning of treatment of infants and after four weeks in those in whom the splint replaces treatment in cast. This daily exercise helps to prevent stiffness of the limbs and improves circulation. In this study, redislocation of the hip did not occur when the splint was temporarily removed by the patient's mother.

If the thigh cuff slips below the knee, the lower strap on the cuff should be tightened, or abduction of the thighs increased. Alternative measures are shoulder straps or an elastic pelvic belt with elastic straps fastened to buckles on the thigh cuffs. The use of a plastic cloth beneath the cuffs will keep them clean and help to prevent slipping. An elastic girdle is frequently needed in older patients. When hyperabduction is indicated, the brace may be bent with bending irons and shoulder straps applied to hold the brace snug.

The mother must be instructed how to apply the brace so as to allow the motion of the crossbar necessary for sitting and lying down. The cuffs can be marked "right" and "left" for the mother's convenience.

DYSPLASIA

The results in twenty-two patients with dysplasia of the hip were uniformly excellent after nighttime splinting for an average of six months. There were two males and twenty females in this group. The earliest age at which treatment was begun was one and one-half months and the oldest, twenty-two months. The average age was seven months. The right hip was involved in six patients, the left in thirteen patients. Three patients had bilateral involvement. The acetabular index before treatment was 22 to 40 degrees, the average being 34 degrees; the acetabular index after treatment was 18 to 28 degrees, the average being 21 degrees. The average period of follow-up was thirteen and one-half months.

FIG. 7-A

FIG. 7-B

Fig. 7-A: At four months of age, patient has untreated congenital dysplasia of the left hip.
Fig. 7-B: Roentgenogram shows result after ten months of nighttime splinting.

A girl, four months old, had dysplasia of the left hip (Fig. 7-A). The left epiphysis was small; the acetabular index on the left side was 33 degrees. An abduction splint was worn only at night for ten months with the result shown in Figure 7-B. The acetabular index after treatment was 18 degrees. Clinical and roentgenographic examination sixteen months later revealed a normal hip.

DISLOCATION OF THE HIP

In forty-one children, all female, with dislocation or subluxation of the hip splinting was the primary method of therapy. The earliest age at which treatment was started was one and one-half months, the oldest being thirty months. The average age was seven months. The splint was worn full time for an average of five months and then at night only for another four months. The shortest period of follow-up was two and one-half months; the longest was fifty-three months and the average was twelve months. As judged by the Ponseti classification, the early clinical results were good, with no symptoms in thirty-nine (94 per cent) and some limitation of motion in two (6 per cent). Early results as seen by roentgenogram were good to normal, according to Severin's classification, in thirty-two (77 per cent) (Fig. 8-C) with aseptic necrosis or fragmentation of the femoral epiphysis occurring in five (12 per cent), moderate deformity in three (9 per cent), and redislocation in one patient (2 per cent). In the one patient with redislocation, a successful result was obtained by closed reduction and immobilization. Gradual abduction splinting failed to reduce the dislocation in two patients, one fifteen months old and one nine months old. Good results were obtained in both patients after closed reduction, immobilization, and later splinting.

Splinting was successful in three patients, five, five, and eight months old respectively, in whom previous abduction traction in the hospital had failed. Treatment with the splint succeeded after the Wu pelvic splint had failed in four patients; the children were four, five, six, and eighteen months old. In one patient, thirty months old, abduction traction reduced bilateral dislocations. This treatment was followed by splinting alone without cast. In one patient, adductor tenotomy was performed followed by successful splinting. The average acetabular index was 35 degrees before treatment and 21 degrees after treatment.

FIG. 8-A

FIG. 8-B

Fig. 8-A: At four and one-half months of age, patient has untreated congenital dislocation of the right hip.

Fig. 8-B: Roentgenogram shows result after full-time splinting for three months and night-time splinting for five months.

Fig. 8-C: Roentgenogram made four years and five months later shows excellent results.

FIG. 8-C

A four-and-one-half-month-old girl had a congenitally dislocated right hip which had not been treated. The roentgenogram (Fig. 8-A) showed disruption of Shenton's line, increased obliquity of the acetabulum, and lateral displacement of the femoral neck. Reduction was achieved by gradual abduction splinting. The splint was worn full time for three months, and during the night five months longer. Figure 8-C shows the excellent result four years and five months later.

A nineteen-month-old girl was seen with congenital dislocation of the left hip. The acetabular index was 20 degrees on the right side and 50 degrees on the left. Roentgenograms showed the femoral head to be displaced laterally and superiorly. Splinting was applied and resulted in immediate reduction. Splinting was continued full time for six months and at night for three months. Further night splinting was indicated because of persistent acetabular dysplasia.

In three patients, abduction traction in the hospital failed; subsequent splinting reduced the dislocation.

An eight-month-old girl was seen with congenital dislocation of the left hip (Fig. 9-A). The hip was placed in abduction traction for twelve days; the results were unsuccessful (Fig. 9-B). The hospital staff

FIG. 9-A

FIG. 9-B

FIG. 9-C

Fig. 9-A: At eight months of age, patient had untreated congenital dislocation of the left hip.

Fig. 9-B: Roentgenogram showed unsuccessful results after twelve days of abduction traction.

Fig. 9-C: After seven days of full-time splinting, the dislocation of the hip was reduced.

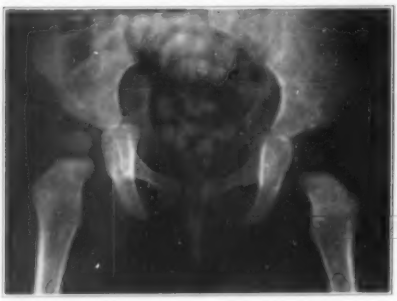

FIG. 9-D

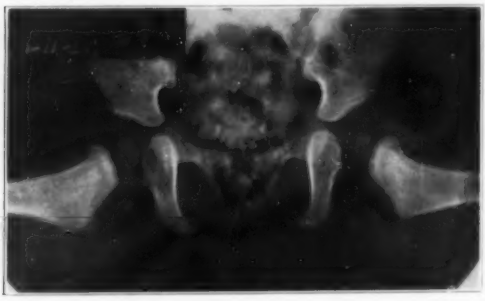

FIG. 9-E

Roentgenograms show results after full-time splinting for six months. Splint had been removed each day for bathing and exercise.

recommended open reduction, but a trial with the abduction splint was allowed. After seven days of splinting roentgenograms showed that the hip was reduced (Fig. 9-C). Full-time splinting, except for removal twice a day for bathing and exercising, has continued. Figure 9-D shows the reduction after only six months of treatment.

A four-and-one-half-month-old girl was brought to the hospital with congenital dislocation of the left hip (Fig. 10-A). Attempted reduction with the Wu splint (Fig. 10-B) was unsuccessful, probably because the pelvic band acted as a fulcrum preventing reduction. (In this series, there were four failures in reduction with the Wu splint; subsequently, reduction was obtained in all four patients with the abduction splint.) Roentgenograms made two years and nine months later show good reduction (Figs. 10-C and 10-D).

A four-month-old girl was first examined in February 1952. The left femoral head was slightly displaced upward and laterally (Fig. 11-A). There was full-time splinting for five months, and at night for four months (Fig. 11-B). After three years and five months there is shortening, widening, and varus deformity of the

FIG. 10-A

FIG. 10-B

Fig. 10-A: Patient was seen with congenital dislocation of the hip at four and a half months of age.
Fig. 10-B: Treatment in a pelvic abduction splint was unsuccessful.

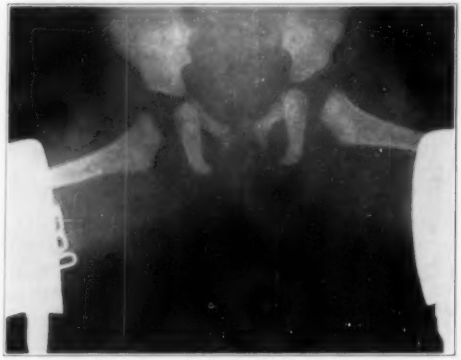

FIG. 10-C

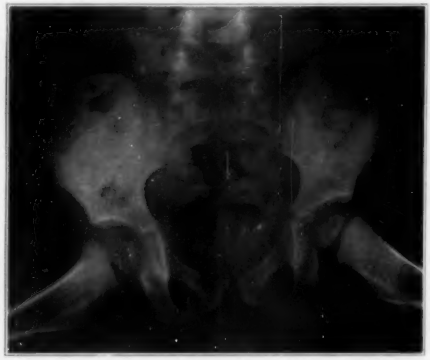

FIG. 10-D

Fig. 10-C: At five months of age, patient's congenital dislocation of the hip had been reduced by means of abduction splinting.
Fig. 10-D: Roentgenogram shows results after two years and nine months of splinting.

femoral neck and incomplete calcification of the femoral head (Figs. 11-C and 11-D). The patient has avascular necrosis.

AFTER CAST

Splinting was used in thirty-one patients after reduction and casting in order to shorten the period of immobilization or to aid in hip development. The earliest age at the beginning of treatment was four months, the oldest was thirty-six months and the average age was sixteen months. In comparison, the average age of the primary group was seven months. The stability of reduction determined the time of cast removal and splinting; it was usually after six to eight weeks. After the patient had been about four weeks in the splint, it was removed daily for bathing and for rotation-abduction exercises. In this series, full-time splinting was continued for six months and at night only for another seven months. The longest period in the splint was seventeen months. The average follow-up was twenty-seven months. Early roentgenograms showed results good to normal in 70 per cent of the patients and moderate deformity in 30 per cent. Fragmentation of the femoral epiphysis was observed in nine patients, or 30 per cent. Four of these healed without deformity and five with deformity.

A roentgenogram shows results after an unsuccessful attempt at reduction by abduction splinting in a fifteen-months-old girl (Fig. 12-A). After traction, closed reduction was done under anaesthesia and a frog-leg cast was applied. Eleven months after manipulation and immobilization there was still incomplete reduc-

FIG. 11-A

FIG. 11-B

Fig. 11-A: At four months of age patient was seen with congenital dislocation of the left hip.

Fig. 11-B: Roentgenogram shows result after abduction splint had been worn full-time for five months, and at night only for four months.

FIG. 11-C

FIG. 11-D

Figs. 11-C and 11-D: Follow-up roentgenograms, made after three years and five months, show shortening and varus deformity of the femoral neck and deformity of the femoral head. The patient had avascular necrosis.

tion (Fig. 12-B). A splint was applied (Fig. 12-C) and worn full time for fifteen months (Fig. 12-D). The improved seating of the femoral head and the result after three years and four months is shown in Figure 12-E.

ANTEVERSION

Nine patients have been treated with the outrigger bar for internal rotation, seven unilaterally and two bilaterally.

A fourteen-month-old girl was seen with untreated bilateral congenital dislocation of the hip (Fig. 13-A). Nine months later, after two closed reductions and immobilization, the dislocation of the right hip was still unreduced (Fig. 13-B). A splint with internal-rotator bar was applied (Fig. 13-C), drawing the femoral head and neck toward the triradiate cartilage. Five months later roentgenograms showed that dislocation of the right hip was reduced (Fig. 13-D). Full-time wearing of the splint was continued for eight months, followed by nighttime splinting. After seventeen months there was improved seating of the femoral head (Fig. 13-E). Clinically, the patient had a stable hip and there was a negative Trendelenberg sign, a full range of motion, no limp, and no complaints.

DISCUSSION

From this study, it appears that the early use of a splint which allows active movement of the hips is an effective treatment in infants and in children up to three years of age. The prognosis, according to A. Bruce Gill, depends upon the degree of defect in the hip

FIG. 12-A

FIG. 12-B

Fig. 12-A: Patient was fifteen months old. There had been unsuccessful results from an attempt at reduction with the abduction splint.

Fig. 12-B: Incomplete reduction eleven months after closed reduction and plaster fixation.

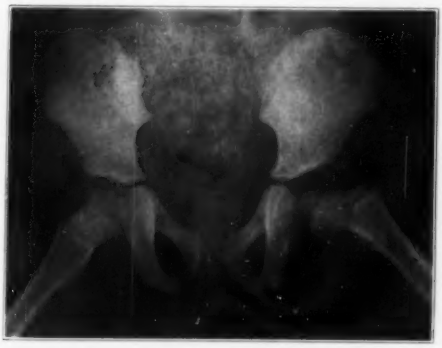

FIG. 12-C

FIG. 12-D

Fig. 12-C: Splint applied.

Fig. 12-D: After fifteen months of full-time splinting.

Fig. 12-E: A roentgenogram made after three years and four months shows the improved seating of the femoral head.

FIG. 12-E

and the ability of the hip structures to grow normally when placed in normal position. Since every patient is different, identical results from the treatment cannot be expected. It is too early to present the desired twenty-year end results such as Heyman and Stephens advise. Yet, the early results reported here show the value of this type of treatment, and they compare favorably with the results of other methods of treatment, such as manipulative reduction and plaster fixation. Of twelve infants under one year of age with congenital dislocation of the hip who were treated at

FIG. 13-A

FIG. 13-B

Fig. 13-A: When the patient was seen at fourteen months of age, there was bilateral congenital dislocation.
Fig. 13-B: Nine months later, after two closed reductions and immobilization in plaster, the right dislocation has not been reduced.

FIG. 13-C

FIG. 13-D

Fig. 13-C: Abduction splint with internal-rotator bar applied.
Fig. 13-D: Five months later the dislocated right hip is successfully reduced.

the Childrens' Hospital by closed reduction and immobilization, after a follow-up of 6.8 years 69 per cent had good functional results, 23 per cent had limp or limitation of motion, 8 per cent had pain. In these, 47 per cent had good to normal results as seen by roentgenograms, 38 per cent had moderate deformity, and 15 per cent had aseptic necrosis or fragmentation of the femoral epiphysis. The results of Bost and associates with the Ponseti splint method in thirteen patients were almost identical.

In splinting, there is absence of the fixity of traction and of months of rigidity in a plaster cast. Orthopaedic surgeons who use the plaster method avoid motion of the hips during the infrequent changes of the cast for fear of redislocation. This concept that the rigid immobilization of the plaster treatment is necessary seems physiologically unsound. In this series, redislocation of the hip did not occur when the splint was removed or with exercises. Motion of the hip within the restricted range allowed by the splint and by daily exercise permits free circulation and therefore seems physiologically desirable. Luck, in 1950, showed that prolonged immobilization of a joint may result in traumatic arthrofibrosis.

When there is marked adductor contracture or upward displacement of the femoral head, an adductor tenotomy or preliminary traction may be indicated. In this series, only one adductor tenotomy was performed. In four patients treated by preliminary traction there was failure of reduction in three. Reduction was then obtained in these three by splinting. Abduction should not be forced in either traction or splinting.

In addition to the physiological advantages of splinting, this method is convenient for the mother and comfortable for the patient.

FIG. 13-E

After seventeen months there was improved seating of the femoral head.

In dysplasia of the hip, a few months of night splinting gave good results. The best time for treatment is at an early age before the time of easy acetabular response has slipped by.

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DISCUSSION

DR. A. B. FERGUSON, PITTSBURGH, PENNSYLVANIA: This is an early report on the use of a special splint for the purpose of gradual abduction which allows considerable motion of the femoral head and acetabulum. In cases of dysplasia, when the femoral head has a normal relationship to the acetabulum, its use appears to be followed by improved development of the joint as measured by the acetabular index. In subluxation, when the femoral head lies laterally in the joint but has not ridden over the limbus, its use also appears to result in adequate development of the joint. In older patients and in those with definite dislocations, that

is, when the femoral head has ridden over the limbus and when a small area of bone condensation just superior to the acetabulum may indicate pressure from the head, one encounters with the use of the splint the usual difficulties.

In our experience, tight flexors are much more of a problem than adductors in dislocated hips. Abduction causes the femoral head to slide further along the ilium or to press tightly against it or against the limbus. We have found axial traction in line with the trunk a necessity in order to accomplish reduction without force.

Abduction as a position necessary for a deep seating of the femoral head in the acetabulum and for development of the joint should not be confused with the maneuvers necessary to place the femoral head beneath the acetabular rim.

The splint with its universal joints in the thigh cuffs and extension bar is an improvement over other similar types. One suspects that it is unnecessarily complicated for the treatment of dysplasia when a simple Frejka pillow or double diapers pinned to the mattress might suffice. It obviously cannot answer all aspects of the problem of dislocated hips, for there are other factors besides abductor tightness.

However, this is a good report on the use of the splint wherein the author shows its successful use when other devices have failed. Further follow-up will determine its true place in orthopaedic surgery.

Dr. Wesley H. Burnham, Minneapolis, Minnesota: Formerly, the general practitioner and the pediatrician were not trained to diagnose hip dysplasia in infancy, and the orthopaedic surgeon did not see the child at an age when treatment is most simple and successful. At the present time, we in Minnesota usually see congenital hip disease in infancy and before the walking age.

Adolf Lorenz objected to early treatment of hip dislocation on the basis of the problem of keeping the child clean. He delayed treatment until a later age and then employed a traumatic procedure for reduction. After he demonstrated his method in this country in 1902, Ridlon employed the so-called bloodless reduction for a short time but then abandoned it because of the many severe complications frequently accompanying trauma. In 1935, Dr. Albert Freiberg remarked that forceful manipulation should be relegated to the past, and that proper positioning in abduction should result in reduction. In 1940, Hilgenreiner carried this thought further when he exclaimed "Away with plaster bindings!" Charles Chappel of Philadelphia, many years ago, advocated treatment of hip dysplasia in the newborn infant by pinning the diapers to the bed in a fashion which held the hip in a frog-leg position. In 1947, Prof. Frejka presented to this Academy his pillow splint, designed to produce slow gentle stretching of the abductor tightness and also to position the hip for reduction and for development of the femoral head and the acetabulum. In 1953, Nicholson, Kopell, and Mattie demonstrated the impairment of blood flow about the hip caused by the position of forced abduction as evidenced by angiographic studies.

An ideal splint for treating congenital dysplasia of the hip, with or without dislocation of the femoral head, before walking age, would include the following features: (1) the adductor tightness should be stretched slowly and gently, and the splint should adjust to the increasing abduction and to growth; (2) the active exercise of the child should be limited as little as possible; (3) toilet care should be easy; (4) the splint should provide control over the femoral rotation when desired; and (5) the adjustment of the splint should be as simple as possible.

The splint presented here by Dr. Ilfeld is for an enlightened age when hip dysplasia is both recognized and treated during the early months of life. He has demonstrated with his splint that dislocation of the hip can be reduced by slow abduction of the hip into the frog-leg position, and that the development of the dysplastic hip, both acetabulum and femoral head, is favored by this position. With this splint, a position of gradually induced wide abduction and internal rotation with the "outrigger" can be maintained while permitting active exercise and ease of toilet care. Although I have used the Frejka splint with gratifying success for eight years, I realize that it does not offer control of femoral rotation. Other splints now in use also lack this necessary feature. Dr. Ilfeld's splint seems to me to fulfill the criteria for a satisfactory device and to have proved to be successful in his hands.

The Immobilizing Efficiency of Back Braces*†

Their Effect on the Posture and Motion of the Lumbosacral Spine

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INTRODUCTION

Supportive apparatus in the form of braces, plaster-of-Paris jackets, corsets, and belts are used extensively in the treatment of low-back disabilities. It is usually assumed that such apparatus has an immobilizing effect. Certainly the braces worn following spine fusion are prescribed with this purpose in mind. However, some apparatus, notably the Goldthwait and Williams braces, fall into a different category, since they are employed to correct excessive lumbar lordosis. In spite of the wide use of back supports and the great financial outlay for such apparatus, little is really known of their function.

For centuries, supports have been worn by persons with gross spinal deformities due to Pott's disease and scoliosis[1]. Indeed many of the braces now employed for low-back pain were originally designed for the treatment of spinal tuberculosis, so that the purposes for which they are now being used are quite different from those for which they were designed.

Although all supports for the back, regardless of design, are constructed on the principle of three-point pressure, the effectiveness of the forces thus developed will vary considerably. In essence there are two counterforces applied by the upper and lower ends of the apparatus and a third, corrective force is located between these. With a hyperextension brace, the corrective force is applied posteriorly, while with the Williams lordosis brace this force is applied anteriorly to the abdomen. Obviously, in those braces in which the corrective force is located essentially midway between the other two forces, the mechanism is reasonably efficient. However, if this force is to be applied to the lumbosacral region, the lower or pelvic lever arm is markedly shortened. Since fixation to the pelvis is inadequate at best, the middle or corrective force must under these circumstances be reduced considerably.

The purpose of this study was to determine as accurately as possible the effect of back supports on the movement and posture of the lumbosacral spine. As the study progressed, a somewhat different concept in back-bracing was evolved, which culminated in the development of a new brace designed to give better lumbosacral immobilization. This brace is now being tested both experimentally and clinically. This presentation is a preliminary report of progress.

METHOD

No attempt was made to test all of the low-back supports which have been described. Representative apparatus in common use were selected. The braces and corsets were made in the brace shop of the Massachusetts General Hospital and were fitted as carefully as possible. The plaster-of-Paris jackets were made by the authors. The Jewett and Williams braces were purchased from the manufacturers and carefully fitted.

The braces tested included the Goldthwait, the Taylor of both rigid and flexible construction (Fig. 1), the Arnold-Abbott (Fig. 2), the Jewett, the chair-back (Fig. 3), and the Williams braces. The study, therefore, included examples of short and long supports, both with and without thoracic bands and lateral uprights.

Tests were performed on subjects with clinically normal spines and no back pain or muscle spasm. This was done in order to ensure that the effects of wearing the brace, whatever they might be, were attributable

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† Based on a paper read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Los Angeles, California, February 2, 1955.

to the apparatus and not to other factors. It must be admitted that the action of the braces under these circumstances may well be quite different from that in the case of a patient with back pain and tenderness.

The subjects were males, ranging in age from twenty-three to fifty-one years. They represented the common body types and ranged in height from five feet, eight inches, to six feet, two inches. One was moderately stout.

As a first step, the subjects were simply observed as they wore the various supports. The behavior of the apparatus with the subjects in the standing, sitting, bending, and squatting positions was noted, and appropriate photographs were taken.

Next, by means of roentgenograms, attempts were made to determine the exact effect of the braces on spinal movement and position. These tests were restricted because of the risk of overexposure to roentgen

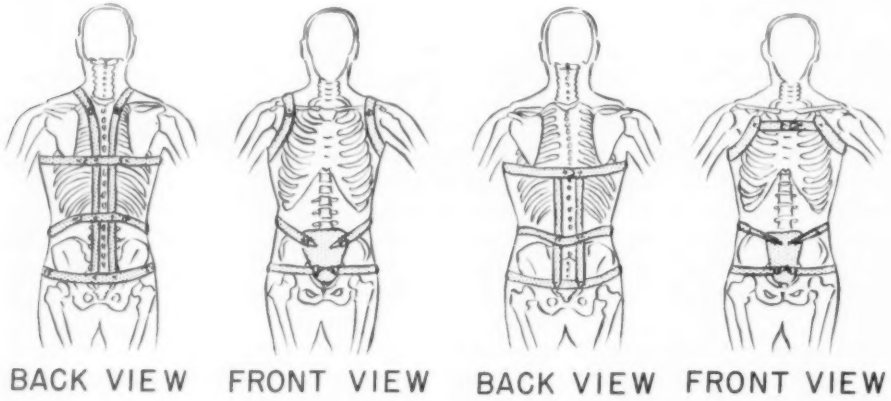

FIG. 1 FIG. 2

Fig. 1: Drawing of the long Taylor back brace on the skeleton. This is an example of a long brace with paraspinal uprights which extend downward from the level of the scapular spines to the pelvic band, located halfway between the iliac crests and the greater trochanters. Each upright is inclined toward the mid-line so that the distance between them decreases from two inches at the pelvic band to one inch in the interscapular region. There are two crossbars in addition to the pelvic band, one on the level of the eighth and ninth thoracic vertebrae, the other six inches below this. Straps pass forward from the tips of each crossbar. Those from the pelvic band and middle crossbar attach to a small abdominal pad measuring six by five by four inches; those from the upper crossbar encircle the corresponding shoulder and buckle to the tips of the uprights.

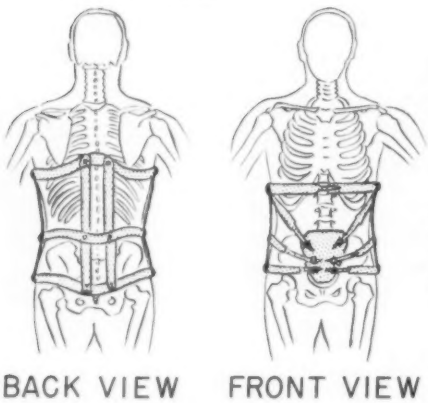

FIG. 3

Fig. 2: Sketch of the Arnold-Abbott brace on the skeleton. There are two paraspinal uprights to which are attached three crossbars. The lowest of these, the pelvic band, lies midway between the iliac crests and greater trochanters. The middle crossbar is flexible and is molded and shaped to follow the iliac crests. The upper band is at the level of the inferior angles of the scapulae and curves forward and upward beneath the axillae to corresponding points beneath the clavicles where the free ends are joined by a strap. The abdominal pad is secured by straps extending forward from the tips of the two lower crossbars.

Fig. 3: Sketch of a chair-back brace on the skeleton. This is a short brace with four uprights, two paraspinal and two mid-lateral, and three crosspieces. The lowest crossbar or pelvic band is at the level of the sacrococcygeal junction posteriorly but curves upward and forward to lie midway between the iliac crests and the greater trochanters in the mid-lateral line; the middle crossbar extends forward along the iliac crests; the upper one is situated at the level of the inferior angles of the scapulae. Each crossbar is curved and shaped to avoid bony prominences. The upper and lower ones are secured to the lateral uprights while the middle one is free at both extremities and medial to the lateral uprights so that it may fit snugly above the iliac crests.

This brace is secured to the body by four pairs of straps, a chest strap secured to the upper crossbar and three pairs of straps which extend from the ends of the crosspieces to the abdominal pad which measures approximately six by five by four inches.

radiation. Hence only lateral views of the subjects standing and bending were made. A standard technique was adopted; a film fourteen by seventeen inches was used with the cassette mounted in a vertical holder. This holder could be rotated on a horizontal axis in such a way as to permit adjustment of the plate to the desired angle; at the same time it could be raised or lowered so that the cassette and the x-ray tube were always adjusted at the level of the iliac crests. The distance from the roentgen tube to the cassette was maintained at four and one-half feet; the subjects stood as close to the cassette as possible. The slight errors due to parallax were therefore the same for each subject and the effects of the various braces on the spinal motion of a given subject were comparable. Some difficulty was encountered in obtaining roentgenograms of sufficient clarity to visualize the outline of the sacrum. A Lysholm grid was used in all instances.

The movement between adjacent vertebrae in the lumbar region was measured in the following manner. For each vertebra a line was drawn through the tips of the two most anterior projections of the anterior surface of the centrum. The angles formed by the intersections of the lines drawn on adjacent vertebrae were measured and any changes in these angles [formed by the intersection of these lines] were recorded as the amounts of motion occurring at the intervening interspaces. For the sacrum the line corresponding to its anterior surface was derived by selecting two points through which to draw the line. One of these points corresponded to the most anterior prominence of the first sacral vertebra; the other was the bony prominence corresponding to the junction of the first and second sacral vertebrae or of the second and third, depending on which point was best visualized on all of the roentgenograms of a particular subject.

Measurements of spinal movement by means of roentgenograms are notoriously inaccurate. In to-and-fro movement, that is, from complete extension to complete flexion, Tanz found "by repeating the roentgenograms and measurements of several subjects" that "the results of these repeated observations usually agreed within two degrees". Due consideration must be given to the existence of such errors in interpreting the roentgenographic measurements.

Furthermore, since there is much individual variation in the amount of motion in the lumbosacral spine of normal subjects, as shown by Tanz and others, roentgenographic studies were obviously of very limited value for the present study. The effect of a group of supports could only be compared on the same subject. However, to test ten braces on the same subject would have resulted in far too much roentgen exposure.

To obviate this, Kirschner-wire markers were inserted into the spinous processes of the appropriate lumbar vertebrae and into one of the posterior superior spines of the ilium, an adaptation of the method used by Inman and his colleagues in their study of the shoulder joint[3]. The change in the angles formed by adjacent wires offered a reasonably accurate method of recording the motion occurring at the intervening interspace. This technique permitted repeated determinations, both with and without supports.

The subject stood before a grid screen (Figs. 4-A and 4-B) upon which there were lines indicating successive angles of 15 degrees from the vertical in the direction of forward bend. Photographs and motion pictures were used to record the movements of the subject and the projecting wires. The center of the camera lens was adjusted to the same level as that of the central wire when the subject was standing. The distance from the camera lens to the subject was twelve feet. Since the wires were moving in a plane at 90 degrees to the focal axis of the lens, and since the angles being recorded were those described by the wires one with another, errors due to parallax were minimal.

When the subject was sitting, the camera was readjusted to keep the lens on a level with that of the middle wire.

The angles between the wires were determined by projecting the photographs or the motion pictures on a ground-glass screen and marking two points on a sheet of tracing paper on the image of each wire. Each pair of points was subsequently connected by a straight line, and the angles formed between these lines were measured by means of a protractor and parallel rule.

In addition, the angle formed between the wire in the pelvis and one of the horizontal lines on the screen was determined. This served as a rough measure of pelvic rotation. The angles measured between the pelvic wire and the horizontal at various degrees of forward bending were directly proportional to but not equal to the angles of hip flexion associated with each of the positions investigated. Since there is considerable backward shift of the pelvis during forward flexion with the knees straight (the backward shift being a compensatory movement aimed at maintaining the center of gravity over the feet), the lower extremities are inclined backward from the vertical. Hence the angle of hip flexion was greater than that recorded between the pelvic wire and the horizontal in all positions of forward bending.

In order to measure the amount of motion of the spine and pelvis, a base line was selected and motion recorded as degrees of flexion or extension from this level. Accordingly, the angles formed by adjacent wires with each other and by the pelvic wire with the horizontal *in the standing position without apparatus* were used as zero for each interspace and for pelvic rotation. It was thus possible to record the changes produced by the various supports in the standing posture and during bending, sitting, and squatting in terms of flexion or extension from this zero line.

There were several disadvantages inherent in this technique, in addition to the difficulties encountered in finding subjects and getting wires properly inserted. For instance, the subjects grew fatigued and the local anaesthesia tended to wear off. Although the wires were not deformed visibly by tension of the soft tissues, it

was possible that this tension altered spinal motion. Finally, many of the braces had to be modified in order to prevent the uprights or crossbars from impinging on the wires. These modifications consisted in offsetting short segments of one of the uprights or crossbars. They did not change the contour or rigidity of the apparatus, but of course they did alter the location of pressure from the apparatus for the particular area of the back involved. It was difficult to assess the influence of these factors on the results obtained.

In modifying the plaster-of-Paris jackets, appropriately placed slots were cut in the plaster to accommodate the projecting wires. By splitting the jacket in the sagittal plane instead of in the conventional frontal plane, the application and removal of the jacket were facilitated.

For the roentgen studies of spinal movement roentgenograms in the lateral projection were made with

FIG. 4-A

FIG. 4-B

Figs. 4-A and 4-B: Subject standing and bending before grid screen. Kirschner-wire markers are inserted in the spinous processes of the second, third, and fourth lumbar vertebrae and in the left posterior superior spine of the ilium. Note the excursion of the wires occurring with 30 degrees of trunk bend. (Due to technical error no marker was placed in spinous process of the fifth lumbar vertebra which was small and difficult to locate.)

the subjects standing in various degrees of forward bending as determined by a plumb line and protractor. For the wire studies, a similar technique was employed when still photographs were being made. The moving pictures were taken, however, with the subject making a series of forward bends. The angles were then measured by selecting the frame which showed the subject in the proper degree of forward bend. It was our impression that the subject's spine was not necessarily held in the same position every time that he bent to a given position, but this has not been investigated. Repeated determinations of the angles at the lower lumbar interspaces by the Kirschner-wire technique revealed that, in the same positions and with the same apparatus, there was a wide spread in the values recorded. The results must therefore be interpreted with caution.

In order to determine the forces produced between the back and the supports at various levels, pressure-recording devices were developed with the assistance of the Department of Civil Engineering at the Massachusetts Institute of Technology. Simple hydraulic gauges with attached pressure shoes to make contact with the back were tried first, but these proved unsatisfactory. The pressure shoes were too large, and the gauges were not sufficiently sensitive. Subsequently, smaller and much more satisfactory devices were developed which employed electrical strain gauges and a recorder.

Each pressure-recording device (Fig. 5) was composed of a cantilever beam clamped at its fixed end to the portions of the brace under investigation by means of a mounting block. Attached to the free end of the lever

was a pressure foot which could be adjusted forward or backward in order to bring it in contact with the back. Any force applied to the pressure shoe would then produce a bending strain in the cantilever. By means of two strain gauges * cemented to the cantilever and connected to a Sanborn recorder, any force applied to the pressure shoe could be recorded in the form of a curve.

With this apparatus it was possible to record the forces developed simultaneously at five different levels on the uprights or crossbars of a brace.

In addition, devices employing the same principles were made to record the force exerted by the shoulder straps, abdominal pads, and the like where they made contact with the body. These devices proved unsatisfactory since they could not be adapted to the widely different contours of these parts of the body. In retrospect, it would have been preferable to record tension in the straps rather than the force between the straps and the body surface.

The recording devices which were clamped to the uprights proved reasonably adequate. However, with

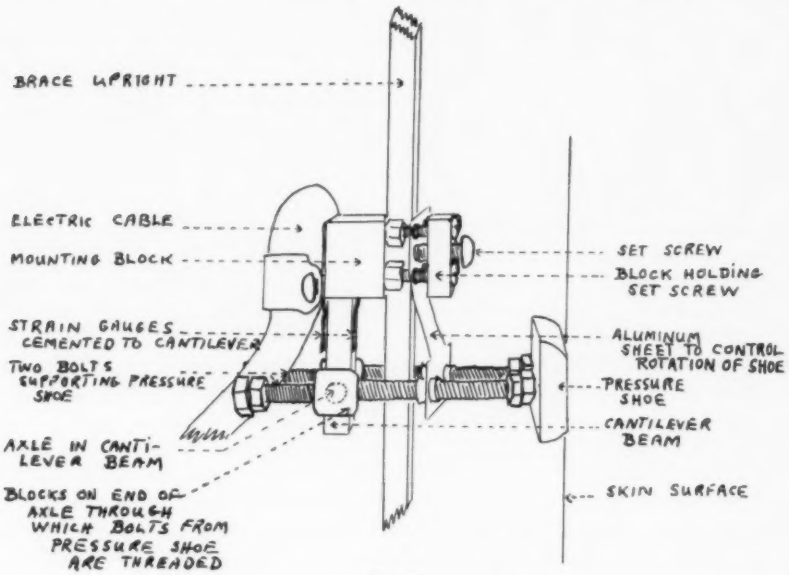
BRACE UPRIGHT
ELECTRIC CABLE
MOUNTING BLOCK
STRAIN GAUGES CEMENTED TO CANTILEVER
TWO BOLTS SUPPORTING PRESSURE SHOE
AXLE IN CANTILEVER BEAM
BLOCKS ON END OF AXLE THROUGH WHICH BOLTS FROM PRESSURE SHOE ARE THREADED
SET SCREW
BLOCK HOLDING SET SCREW
ALUMINUM SHEET TO CONTROL ROTATION OF SHOE
PRESSURE SHOE
CANTILEVER BEAM
SKIN SURFACE

FIG. 5

Pressure-recording device mounted on the brace upright. The principal elements of this device are the cantilever beam clamped to the upright at one end, the pressure foot, and the strain gauges. The pressure foot is adjusted against the skin surface by turning the bolts. Any increase in pressure between the subject's body and the pressure shoe produces a backward deflection of the cantilever. This deflection causes a change in tension of the electrical strain gauges cemented on the cantilever. By appropriate electrical connection to the Sanborn Recorder this change in tension is recorded as a curve from which the pounds of force on the pressure shoe could be determined.

their attached electrical cables, they increased the weight of the apparatus considerably. Furthermore, it proved impossible to adjust the pressure shoes so as to reproduce the contour of the brace exactly. Finally, these recording devices were of such a size that the pressure shoes could not be placed at exactly comparable levels in all instances due to the presence of crossbars and the like.

In order to determine the force exerted by the plaster-of-Paris jackets, holes were cut in the plaster in the appropriate places, and the recording devices were mounted on duraluminum strips bolted to the outside of the jacket. By this method the pressure feet could be adjusted to fit into the holes and record the forces developed at these points.

It was not possible with these instruments to measure the forces developed by corsets or similar apparatus.

* SR-4 A-8 strain gauges were used. These are fine, hair-like wires whose electrical resistance varies directly with the tension applied to them. When appropriately secured to the cantilever and connected to the recorder as a Wheatstone bridge in balance, changes in their resistance caused by the bending stresses on the cantilever disturb the balance in the bridge and produce a flow of current and a corresponding deflection of the stylus of the recorder. The gauges were compensated for temperature and sealed in wax to obviate the effects of moisture.

Inevitably the presence of recording devices on the supports changed their behavior to some extent. The techniques employed were obviously crude and the discrepancies in some of the results could be attributed to these technical defects.

Forward bending as ordinarily recorded in clinical practice represents a compound movement involving flexion of both the hips and of the spine. In these experiments, the amount of forward bending was estimated as the angle formed between the vertical and an imaginary line drawn from the sacrum to the thoracolumbar junction. This reference point proved more satisfactory than using one higher on the spine, for there was wide variation in dorsal flexibility. An occasional subject could approach the horizontal or 90 degrees of flexion with his shoulders but the lumbar region did not attain more than 50 to 60 degrees of forward bending.

In order to obtain a graphic record of forward bending to be correlated with determinations of force, an automatic goniometer was developed (Figs. 6-A and 6-B). This was composed of two parts: a potentiometer secured to the thigh at the level of the hip joint, and a rod projecting downward in the axis of the trunk and secured rigidly at its upper end to the thorax. The rod was attached to the axle of the potentiometer by means of a sliding coupling. With this arrangement flexion or extension of the trunk or hips would rotate the axle of the potentiometer, changing its resistance and thereby causing a flow of current and a corresponding deflection of the stylus of the Sanborn recorder. The resulting curve was calibrated in degrees and a continuous recording of both pressure and bend could thus be made. The goniometer proved reasonably satisfactory, but some difficulty was encountered in securing the potentiometer rigidly to the thigh. The size and contour of the thigh changes as the result of variations in the tone of the thigh musculature. Inevitably some change in the relationship of the potentiometer and the thigh resulted, introducing an error of approximately plus or minus 5 degrees in the measurements of bending.

RESULTS

Observation of the action of the various types of supports with the subjects in different positions indicates that apparatus which is well fixed to the chest but inadequately attached to the pelvis tends to produce a concentration of force in the upper lumbar and thoracolumbar regions as the trunk goes into flexion. The lower end of the apparatus lifts away from the sacral region (Fig. 7), limiting motion of the upper levels and leaving the lumbosacral segments unsupported. This behavior was noted with the Taylor and the Arnold-Abbott braces, and with plaster jackets.

In contrast to these are the short supports, such as the Goldthwait and the chair-back braces and corsets. These have little if any fixation to the chest but are relatively well secured to the pelvis. With these the tendency for the lower end of the apparatus to pull away from the body is much less (Fig. 8). Quite obviously relatively little force is exerted in this instance but what pressure is developed is maintained at the lumbosacral junction.

Rather to our surprise, but in accordance with the previously observed behavior of back supports, roentgenographic studies of spinal motion revealed that some braces actually increased lumbosacral motion, when motion with the brace was compared with the motion measured in control bending without support (Fig. 9). This effect seemed to be related to the concentration of force in the thoracolumbar region produced by the longer braces. By limiting spinal flexion in this region, compensatory movement presumably occurred below. This effect became manifest usually in the higher degrees of forward bending, but in some instances it was apparent at 30 degrees (Figs. 23 and 24). It did not occur with all long braces nor with every subject, but the fact that a brace improperly selected or fitted might be deleterious had not occurred to us. Needless to say, this effect may not be present in patients having back symptoms. This has not been investigated.

Although it was appreciated that the range of motion in the lower lumbar interspaces varies considerably, as emphasized by Tanz, the present study suggests further that in normal forward bending there are other variations. These include such things as the amount of hip motion and the point in the arc of forward bending of the trunk at which the flexion possible at a given interspace is expended.

The site in the body where the greatest flexion occurs during forward bending varies greatly with the individual. At one extreme there is the person who bends forward primarily by hip flexion (Fig. 10), while at the other there is the so-called "ham-strung" individual who appears to bend forward primarily by spinal flexion (Fig. 11). Between these

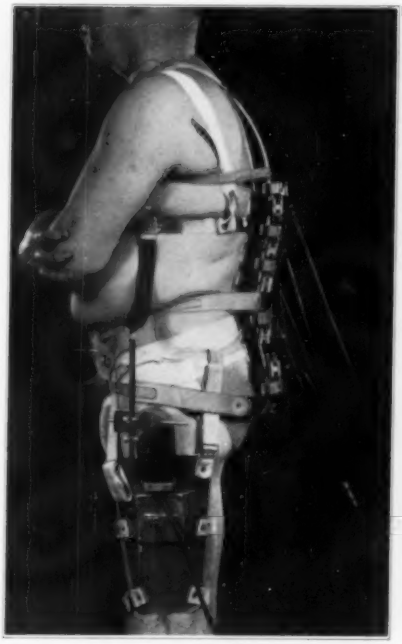

FIG. 6-A

FIG. 6-B

Fig. 6-A: Side view of a subject wearing Taylor back brace with recording devices clamped to the uprights. Note the goniometer on the plate strapped to the left thigh, the vertical rod secured to the thorax, and the sliding coupling on the axle of the goniometer which permits both horizontal and vertical movements of the vertical rod with reference to the goniometer.

Fig. 6-B: Subject bending forward while wearing brace and recording devices. Note the relationship of the pressure shoes to the back. Maximum indentation of the skin is at thoracolumbar junction, while the pressure shoes at top and bottom of the brace are not even in contact with the skin. The action of the sliding coupling on goniometer can be seen.

extremes are all manner of variations. Since only a few subjects have been studied, it is not possible either to classify these variations or to assess what, if anything, is their significance. Many of them are difficult to explain and may even represent experimental errors. However, peculiar phenomena, such as extension of the fifth lumbar interspace during the first 15 degrees of forward bending, were noted on more than one occasion. One rather arresting finding was that a number of subjects seemed to expend the full range of flexion available in the lumbosacral joint during the first 30 degrees of forward bending of the trunk. This suggests that an effective support for the immobilization of this joint should exert its effect during the first 30 degrees of trunk bend.

Of interest also is the amount of lumbar flexion observed during sitting, as previously observed by Keegan. When this was compared with the lumbar flexion associated with maximum forward bending (Fig. 12), it was apparent from the few incomplete studies made that even in the erect sitting position a substantial amount of flexion occurred. In the slumped position, on the other hand, flexion between the fourth and fifth lumbar vertebrae actually exceeded that observed during maximum forward bending, while at the remaining lumbar interspaces it was somewhat less but still considerable.

These observations emphasize the importance of sitting as a cause of stress on the low back and suggest that a support for the lumbar and lumbosacral portions of the spine should be effective in the sitting position as well as during forward bending.

Although for reasons previously mentioned our studies on the effect of back supports on the posture and movement of the lumbar spine have been rather inconclusive, the findings are of interest and worthy of comment.

FIG. 7

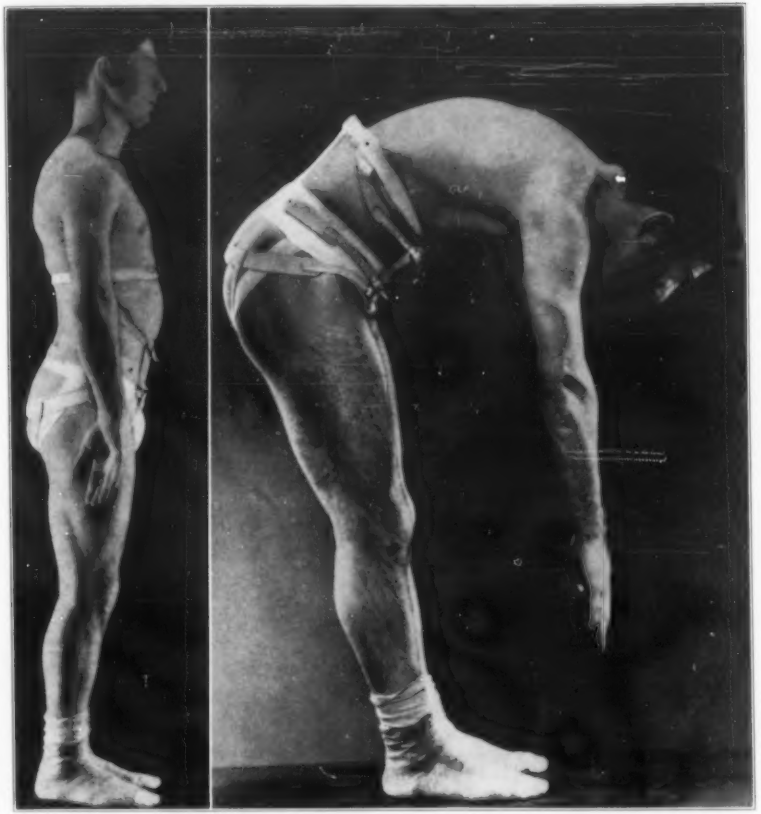

FIG. 8

Fig. 7: Subject standing and in a position of full forward bending wearing a rigid Taylor brace with peroneal straps. Note that the lower end of the brace pulls away from sacral region, concentrating force at the thoracolumbar junction.

Fig. 8: Subject standing and bending in the Goldthwait brace with chest and peroneal straps. Note that concentration of pressure is approximately at the lumbosacral level. Spine flexion above this point is relatively free. With this brace during forward bending the force developed between the brace and back is of a low order but it is reasonably well localized over the lower lumbar spine.

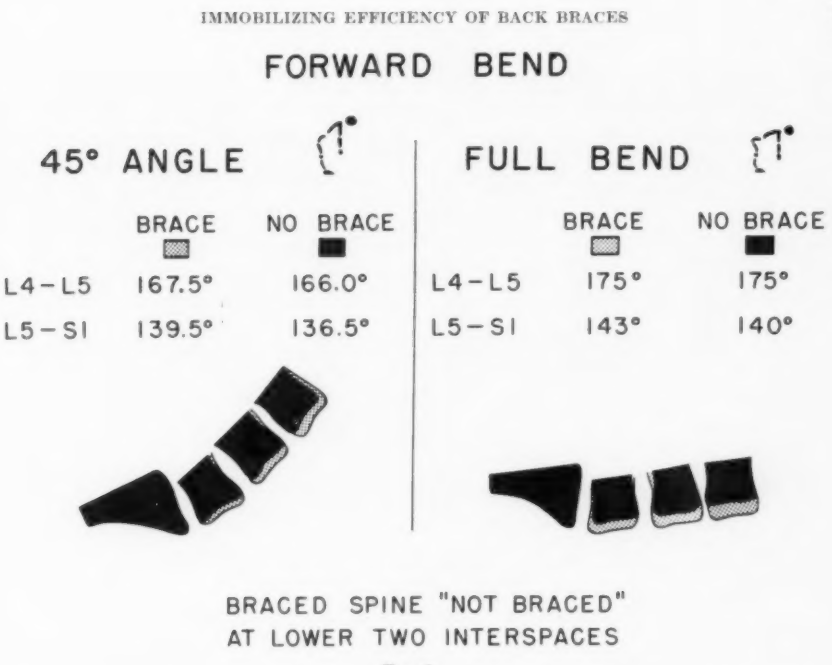

FIG. 9

Tracings of lateral roentgenograms of a subject bending forward to 45 degrees and to the maximum wearing an Arnold-Abbott brace and without any apparatus. The sacral tracings are superimposed. At 45 degrees of forward bending flexion at the fourth and fifth lumbar interspaces was slightly more when the brace was worn. At full forward bending flexion at the fifth interspace was greater when the brace was worn but at the interspace above there was no difference. Although this effect did not occur consistently it appeared to be due to the apparatus which tended to concentrate force against the thoracolumbar region of the back as flexion progressed.

The effect of supports on the position assumed by the lumbar spine in standing was recorded by comparing the position of the spine in each subject with and without support. With but few exceptions the apparatus tested caused flexion of the two interspaces between the fourth lumbar and first sacral vertebrae and extension of the interspace between the third and fourth lumbar vertebrae (Figs. 23, 24, and 25). The factors governing interspace position were not made clear by the tests, although it was thought that undetected localized pressure from the uprights might have been responsible for the extension at the upper interspace. The tendency of a support to produce flexion of the lumbar segments did not seem related to any particular design. Surprisingly enough, the effect of the support on adjacent interspaces in the same spine was occasionally reversed, one being extended and the other flexed, or vice versa.

Irrespective of the standing or starting position, forward bending was accompanied by interspace flexion, except at the third or fourth lumbar interspace where extension sometimes occurred. In general, at the two lower interspaces three effects were observed during forward bending: (1) a reduction in the amount of movement, (2) a change in the arc of movement to either the flexion or extension side of neutral, and (3) although rarely, an increase in total movement. In all of the subjects tested, a striking lack of consistency in the effect of the various types of apparatus was evident, particularly at the two lower interspaces.

There was some evidence to suggest that an adequate abdominal support may be responsible for considerable immobilization; for example the Williams brace, which theoretically should allow free flexion, caused some limitation of lumbar movement during forward bending.

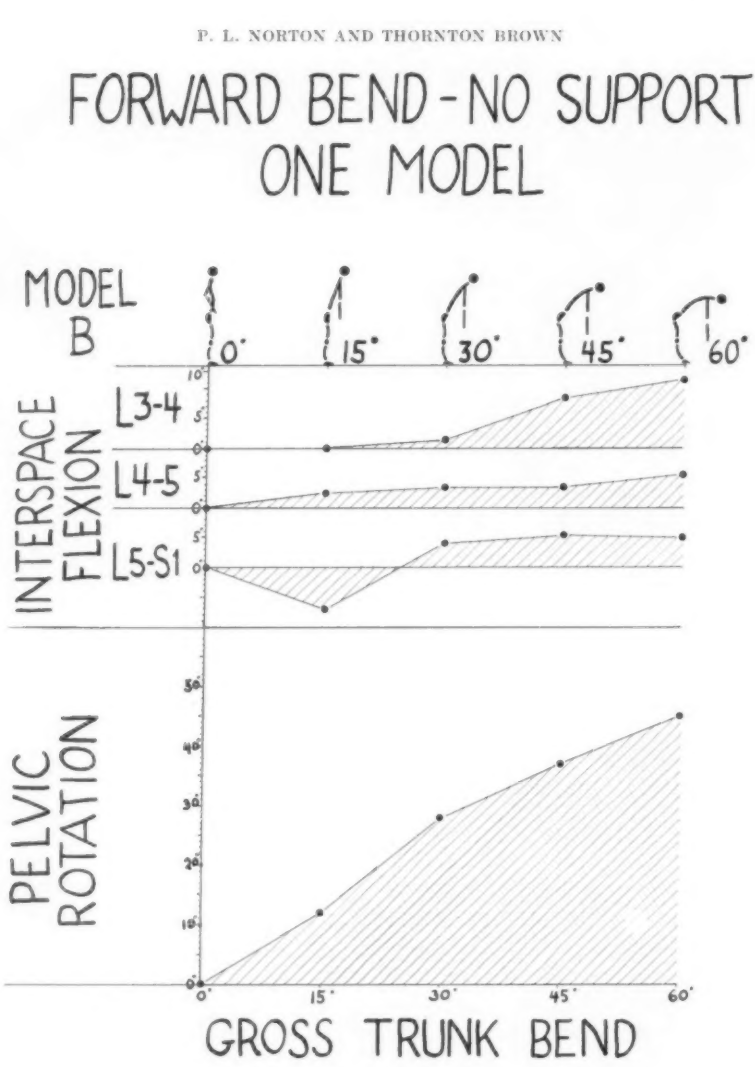

FIG. 10

Motion of the lower three lumbar interspaces and pelvic rotation of subject B during forward bending (abcissa). Zero degrees of interspace motion or pelvic rotation (ordinate) corresponds to the position of each interspace and of the pelvis (as indicated by the Kirschner-wire markers) when the subject was standing. The changes in the relative position of the wires during forward bending reflect the motion of the vertebrae and pelvis, flexion being upward and extension downward. At each interspace the curve indicates the change in the angles formed by adjacent wires. For the pelvis, the curve indicates changes in the angle formed by the pelvic wire with relation to the horizontal plane.

In the sitting position the conventional supports decreased the amount of lumbar flexion associated with both the erect and the slumped position, but none were completely effective in preventing flexion (Fig. 27).

Measurements of force produced against the back by the various types of apparatus were made at several points along the back from the level of the sixth thoracic vertebra to the sacrococcygeal junction. As the result of the different weights of the supports and the involuntary changes in posture of the subjects, it proved impossible to adjust the

starting forces on the gauges at strictly comparable values for all of the supports tested. Furthermore, the inevitable changes in contour of the supports resulting from the presence of the recording devices were variable. Hence, the values obtained could be considered only roughly comparable to those actually developed between the back and a given support in the absence of the gauges. For the same reasons, the forces developed by the different types of apparatus were not strictly comparable.

All of the long braces caused pressure in the lumbar and lower dorsal regions, which reached a maximum as full forward bending was attained. Above and below these levels, as might be expected, the pressure decreased during flexion, since the sacrum and upper

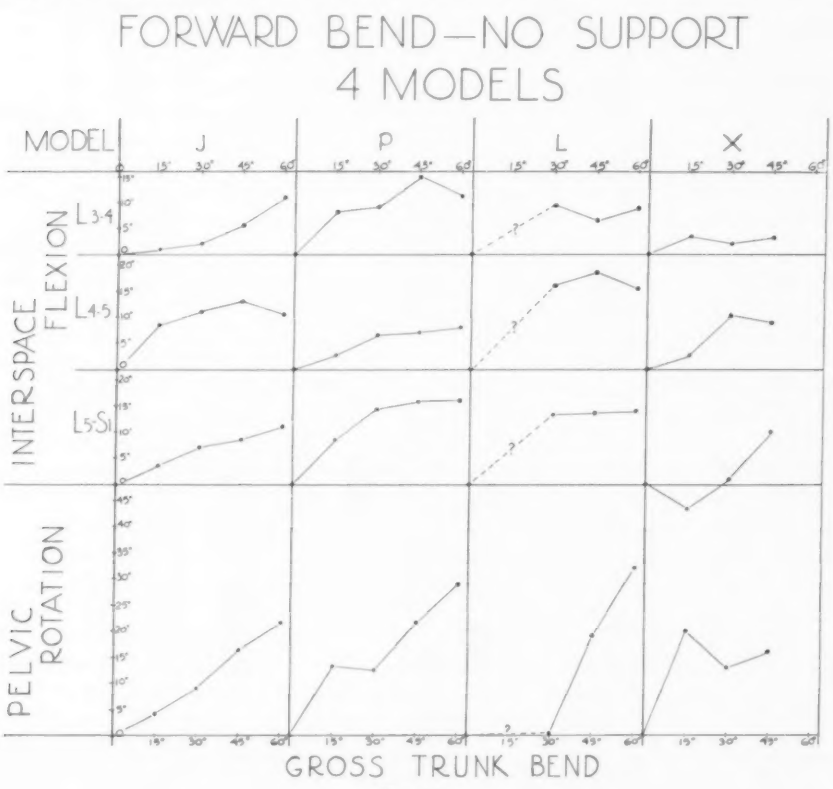

FIG. 11

Motion of the lower three lumbar interspaces and pelvic rotation of four subjects (see legend for Fig. 10). Note the variations in the manner in which flexion occurs at those interspaces in the rotation of the pelvis. For subjects *P* and *L* all available flexion at the fifth lumbar interspace appears to have been expended at 30 degrees of forward bending. Subject *P* who on clinical examination had tight hamstrings and limited forward bending shows the most flexion of the third and fifth lumbar interspaces. The high degree of pelvic rotation exhibited by this subject seems inconsistent with the clinical evidence of tight hamstrings. No explanation for this apparent inconsistency was found. The measurements on subjects *P* and *J* were made with Kirschner-wire markers, while bending roentgenograms were used for subjects *L* and *X*.

dorsal regions moved away from the brace as bending progressed. Some variation in the speed with which pressure was built up by the various braces was recorded but technical difficulties associated with adjusting comparable starting or standing pressures made it difficult to interpret these differences in the early phases of bending (Fig. 29).

The maximum forces recorded at 60 degrees of forward bending in the lumbar region varied considerably, ranging from eighteen to fifty-six pounds. With the short supports,

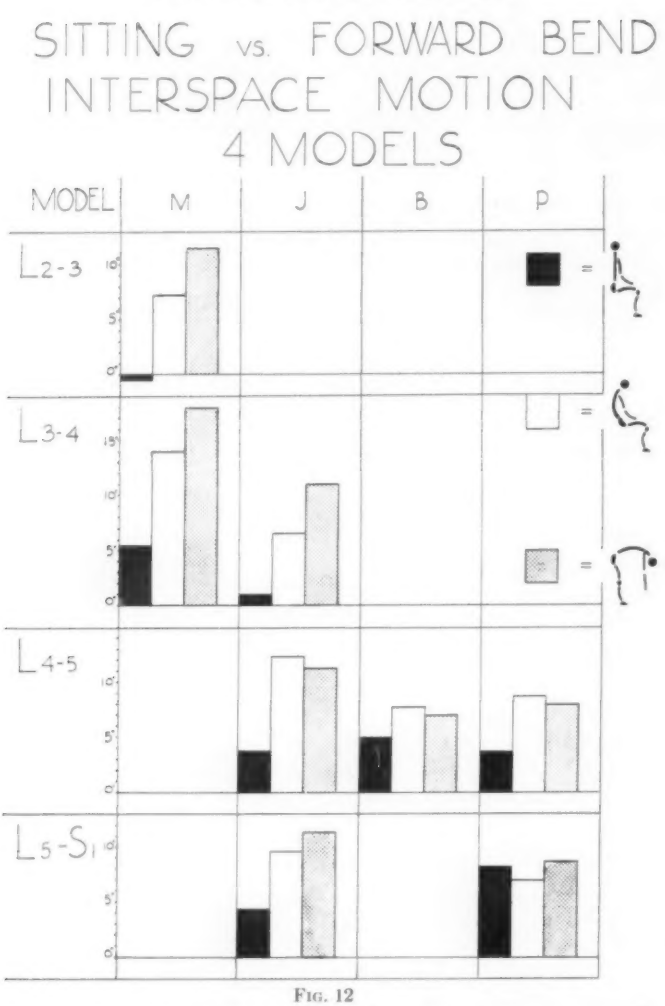

FIG. 12

Lumbar flexion of four subjects in the erect and slumped sitting positions compared with their lumbar flexion occurring with full forward bending. Note that at the fourth lumbar interspace in the three subjects tested more spinal flexion accompanied the slumped sitting posture than occurred in full forward bending. Even in the erect sitting position considerable lumbar flexion occurred, notably at the fifth lumbar interspace in subject *P*. The studies on all of these subjects are incomplete for the following reasons: *M*, no wire in the fifth lumbar spinous process; *J*, no wire in the second lumbar spinous process; *B*, no wire in the second or third lumbar spinous processes and the wire in the ilium had been dislodged by the crossbar of a brace before this test was performed; *P*, no wire in the second or third lumbar spinous processes.

such as the Goldthwait brace and chair-back brace, none of the recorded values exceeded thirty-five pounds. With the longer supports, such as the Arnold-Abbott, Taylor, and Jewett braces, and plaster-of-Paris jackets, the pressures ranged from thirty to fifty-five pounds.

There is some indication that the amount of force developed by most of the supports is influenced by the pattern of lumbar flexion. Tests made on subject B (Fig. 29) showed that comparatively small forces were developed with most types of supports. In his case, forward bending was accompanied by minimal flexion of the lumbar interspaces (Fig. 10).

DEVELOPMENT AND TESTING OF NEW BRACES

As the study of back supports progressed, it seemed worth while to try to develop a new brace for lumbosacral immobilization. The objective was to design a brace which would apply sharply localized pressure at this level during the first few degrees of trunk bend and yet be comfortable in the standing and erect sitting position.

Two brace designs were tested. The first, called the reinforced Taylor brace, consisted of a conventional Taylor brace made of spring steel, the uprights having been made rigid by duraluminum reinforcements extending from the level of the third lumbar vertebra to the pelvic band.

The second, referred to as the experimental brace, was designed to produce localized pressure over the posterior superior spines of the ilium by means of a horizontal bar. The usual paraspinal uprights were to be eliminated and replaced with mid-lateral uprights. This region was selected as the pressure point for the horizontal bar, because force applied here was found to build up rapidly. In a simple experiment (Fig. 13), in which a pressure-recording device was advanced gradually against various locations on the back of a subject lying prone on a hard surface, the force developed was measured. By plotting this force against the displacement it was apparent (Fig. 14) that the most rapid increase of force occurred at the posterior superior iliac spines or just caudal to them.

Still another reason for selecting this pressure point was that in this position any tendency of the brace to move cephalad during forward bending served to increase the pressure of the horizontal bar on the projecting posterior superior iliac spines and thus to limit motion.

The experimental brace is made of duraluminum bands one-eighth of an inch thick and three-quarters of an inch wide. It consists of two lateral uprights, following the mid-axillary lines from a point three to four inches below the level of the inferior angles of the scapulae and extending downward to the level of the greater trochanters (Fig. 15). These uprights are connected posteriorly by two horizontal crossbars, the one at the top stabilizing the upper end of the brace, the lower one crossing the low back at or just below the level of the posterior superior iliac spines. Both of these horizontal strips are bent to fit the contours of the back and are tilted slightly to make their surfaces parallel to the sacrum and thorax (Fig. 16).

At the lower end of each upright is a small padded disc so mounted as to rotate in the sagittal plane. These discs prevent undue pressure on the trochanters and also serve as the points of attachment for the lower abdominal straps. Since they are free to rotate, the lower straps can shift their direction of pull as the position of the thighs changes during bending and sitting.

The abdominal pad selected is of the large semirigid type (Fig. 17) extending from just below the xiphoid process to the top of the symphysis pubis. It is secured to the uprights of the brace by three straps on each side, one at the top, one at the level of the iliac crests, and one extending from its lower corner to the disc on the upright over the trochanter.

In an attempt to test the efficiency and mode of action of the abdominal pad on an experimental brace the force developed between the lower crossbar and the posterior superior iliac spines was recorded on the same subject under different conditions. Large and small pads in various positions on the abdomen and with different methods of attachment were investigated both during forward bending and slumping in the sitting position (Figs. 18 and 19).

With a small pad, the lower the pad was placed on the abdomen, the greater was the force developed between the lower crossbar and the posterior superior iliac spines, as might be expected. With a large pad, unyielding attachment to the brace uprights by three straps proved more effective than an automatically adjusting method of attachment

composed of cords and pulleys. This latter arrangement consisted in a series of pulleys secured to the brace uprights and the sides of the pads. The pad was secured to the brace on each side by running a piece of clothesline alternately through the pulleys on the pad and on the upright, as a lace is passed through the eyelets of a shoe. By such an arrangement the relationship of the pad and brace was not fixed but could shift as the ropes slid through the pulleys. During forward bending or slumping, the distance between the brace and the pad increased in the lower pelvic area and decreased in the upper thoracic

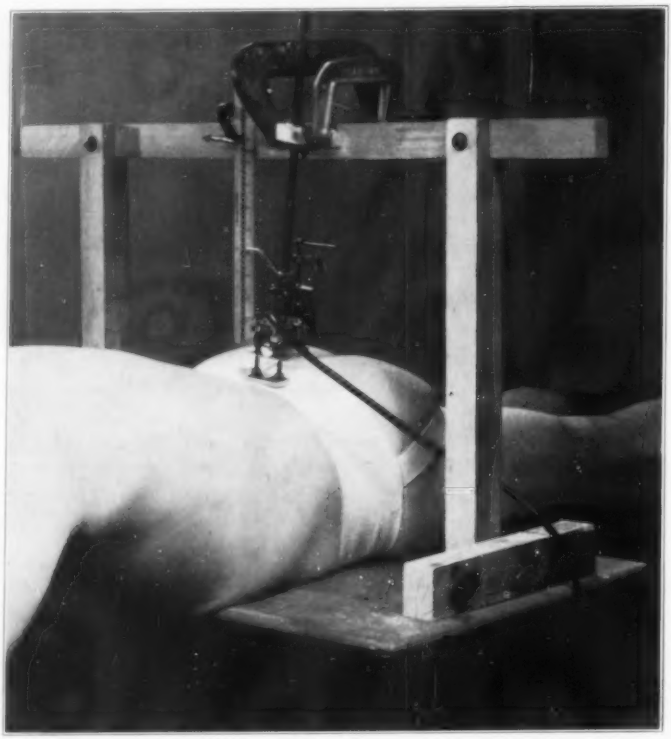

FIG. 13

Apparatus used to investigate the speed with which pressure is built up and the amount of force necessary to produce discomfort at various locations on the back. With the subject prone within the frame, the pressure shoe is adjusted over the desired location, in this instance the left posterior superior iliac spine. The recording device, mounted on a swivel on the end of a threaded rod can be advanced or retracted by turning the rod. For this experiment the force on the pressure shoe was recorded for every quarter inch of advance (See Fig. 14).

portions, with consequent diminution of pressure over the posterior superior iliac spines.

It was concluded that the pad should be as low as possible and that a large pad fixed by three straps was the most desirable, although its superiority over a small pad was apparent only in the sitting position. As previously noted, widespread support of the abdomen has some immobilizing effect on the lumbar spine by itself as shown by the effect of the Williams lordosis brace.

A chest strap of two-inch webbing is attached to the top of the uprights, its tension adjusted so that it becomes taut as flexion occurs and yet it does not constrict the chest while the wearer is standing or is sitting erect.

This experimental brace has the following advantages: (1) By the elimination of the paraspinal uprights, the shifting of the point of maximum pressure during flexion cannot

occur and the immobilizing effect of the brace is maintained at the desired level by the crossbar. (2) The extension of the uprights down as far as the greater trochanters provides a relatively low point of fixation for the inferior abdominal straps. Since this low point of fixation is at the axis of rotation of the pelvis on the thighs, the lower straps tend to keep a constant tension in either the sitting or standing position provided that the lumbar spine is not flexed. In the erect standing or sitting positions the brace exerts little pressure and is comfortable. Lumbar flexion and slumping in the sitting position, on the other hand, are attended by a prompt increase of tension in the lower abdominal straps and a sharp rise of pressure on the posterior superior iliac spines (Figs. 20-A through 20-D).

Kirschner-Wire Tests

Unfortunately, the experimental brace proved difficult to test by the Kirschner-wire

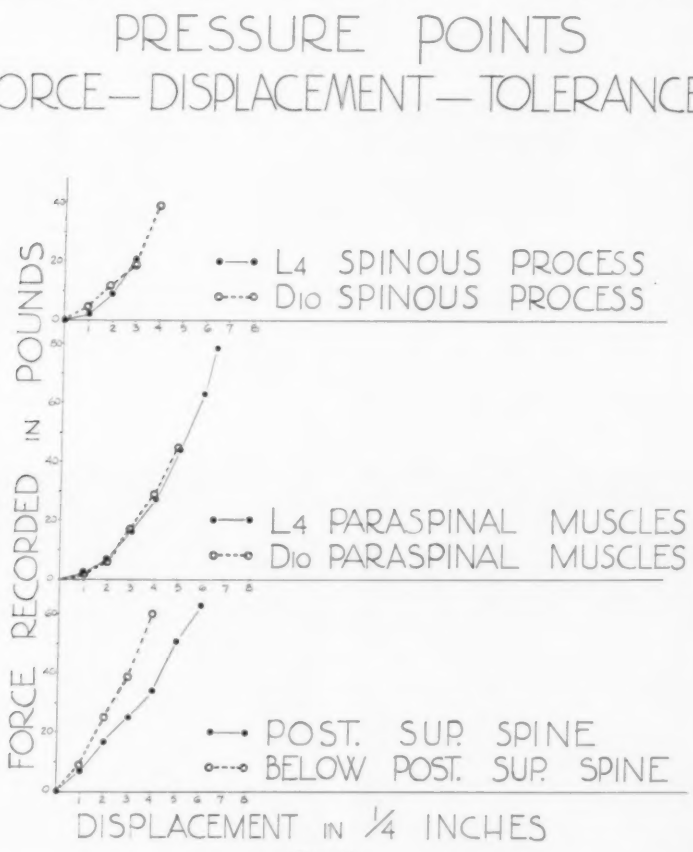

FIG. 14

Results of the experiment with the apparatus shown in Fig. 13. Pounds of force are plotted against advancement of the pressure foot. The slope of the curves indicates the speed with which force was built up at various locations on the subject's back as the recording device was advanced. The end point of each curve indicates where the force became intolerable. As might be anticipated the force is not tolerated well over bony prominences, particularly over the fourth lumbar spinous process. It is well tolerated, however, over the paraspinal muscles at this level which is the site planned for the application of force with conventional braces. The most rapid increase in force occurs with the pressure shoe located just caudal to the posterior superior spine. The meager soft tissue covering this point and the rigid pelvis are of course largely responsible for this result. However, in addition it was noted that when the shoe was at this location, it did not show a tendency to slip cephalad off the posterior superior iliac spine with resulting decrease in force as was the case when the pressure shoe was located directly over this bony prominence.

technique. In order to insert wires in the left posterior superior iliac spine and in the fifth lumbar spinous process, the lower crossbar of this brace had to be offset at these points (Fig. 21). Thus contact of the crossbar with one of the posterior superior spines was eliminated, and the support was robbed of at least some of its effectiveness. To be sure, other braces were also modified but it is unlikely that their effect was materially altered (Fig. 22).

The effects of the various supports tested during forward bending from the erect standing position and also during sitting were compared. During forward bending the effects were as follows:

At the fifth lumbar interspace (Fig. 23): All of the supports caused slight flexion in the standing position except for the experimental brace, which caused extension in both subjects, and the Goldthwait brace, which caused flexion in one subject and extension in the

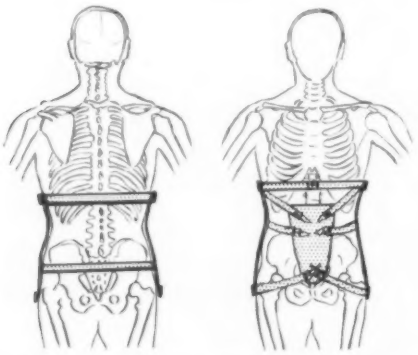

FIG. 15

Drawing of the experimental brace on the skeleton. By eliminating paraspinal uprights all the force applied to the back by the apparatus is concentrated in the region of the posterior superior iliac spines. Whereas conventional back supports seek to avoid pressure over bony prominences, this brace is designed specifically to produce uncomfortable pressure over these bony processes as soon as the allowable limits of flexion are exceeded. The position of the abdominal pad cannot shift since the straps are arranged to pull upward, downward, and laterally without the need for peroneal straps (contrast this with Figs. 2 and 3).

FIG. 16

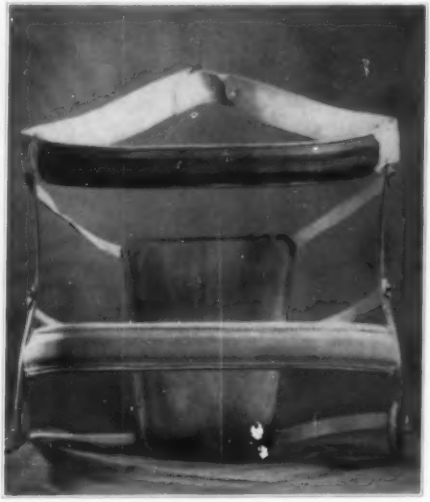

FIG. 17

Fig. 16: Back view of the experimental brace on a subject showing how the lower crossbar rests just caudal to the posterior superior iliac spines. The upper crossbar lies three inches below the inferior angles of the scapulae. Both are inclined slightly so that they lie parallel to the body surface.

Fig. 17: Back view of experimental brace showing lateral uprights, trochanteric pads, upper and lower crossbars, large semirigid abdominal pad, and chest strap.

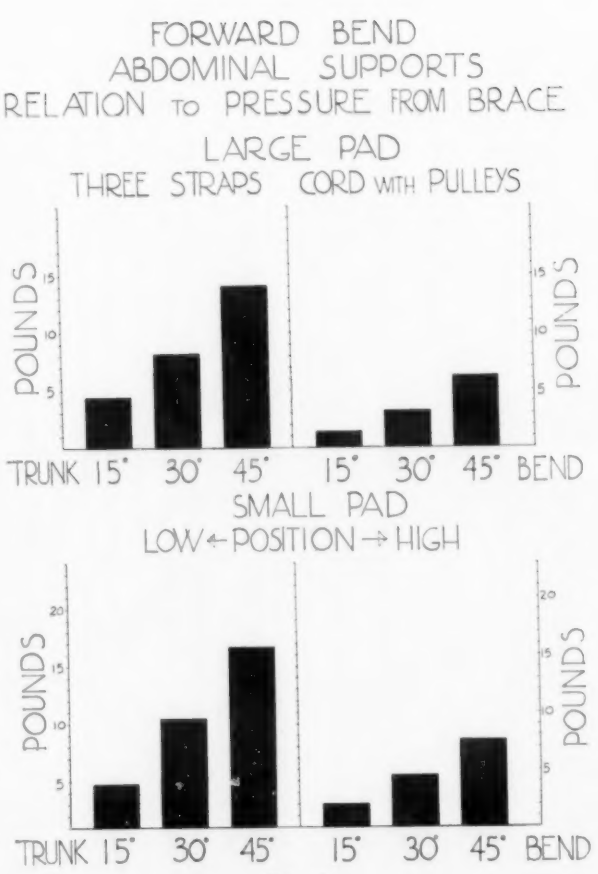

FIG. 18

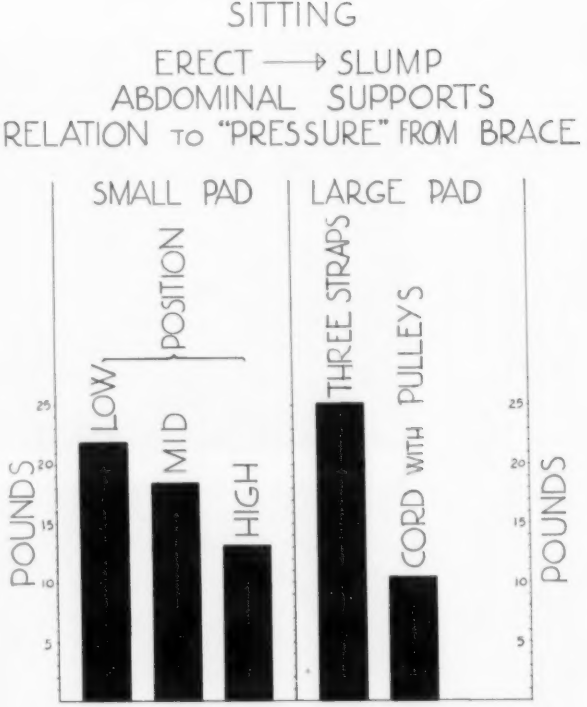

FIG. 19

Fig. 18: Effect of variations in the abdominal supports on the force developed by the experimental brace during forward bending.

Top: The effect of the large semirigid abdominal pad (nine by seven by five inches) attached by three pairs of straps compared with that of the large pad attached by cord and pulleys.

Bottom: Effect of the small rigid abdominal pad (six by five by four inches) secured in the low position at the symphysis pubis and high on the abdomen at the level of the iliac crests.

Fig. 19: Effect of abdominal support on force developed by experimental brace during slumping from the erect sitting position.

other. At 30 degrees of forward bending, all supports caused some limitation of interspace flexion except for the Jewett brace in one subject (P), in whom increased interspace flexion occurred. The reinforced Taylor brace caused the greatest limitation of motion at this level in both subjects. In the subjects in whom the Goldthwait and the experimental brace caused extension of the lumbosacral interspace in the standing position, the effect of the braces at this level during 30 degrees of forward bending was somewhat anomalous. Considerable interspace motion was permitted by these supports but since it started from

FIG. 20-A

FIG. 20-B

Fig. 20-A: Behavior of the experimental brace on a subject in the standing position. Large abdominal pad extends from just below xiphoid process to the symphysis pubis.

Fig. 20-B: In forward bending, the lower straps tighten promptly. Note the indentation of the skin caused by the lower strap and lower crossbar at approximately 30 degrees of forward bending.

a position of extension, the final position after 30 degrees of forward flexion was close to the zero position; that is, the position of this interspace while the subject was standing without support. In other words, the amount of flexion which had taken place between standing and 30 degrees of forward flexion was limited very little, but the arc through which it had occurred had shifted towards extension.

At the fourth lumbar interspace: Most of the supports caused some flexion in the standing position (Fig. 24) except in one subject (J). The explanation for the tendency to extension of this interspace in this individual is not clear. At 30 degrees of forward bending all apparatus caused some limitation of flexion at this interspace except for the Jewett brace in one subject (P). In this instance flexion at this level was increased. The experimental brace at this level performed rather well except on subject P. In his case study the moving pictures revealed that the lower crossbar was located too high with the result that during forward bending its force was brought to bear above this interspace.

At the third lumbar interspace (Fig. 25): Most of the supports caused extension in the standing position which persisted or even increased slightly when the subjects bent forward to 30 degrees. Here also, however, there were some rather striking and unexplained exceptions to this general finding. Presumably at this higher level the force exerted by

most supports was sufficient to cause extension. When this was of an uncomfortable degree as was the case with the plaster jacket, the extension was most marked.

In the sitting position the following effects were observed (Fig. 27):

At the fifth lumbar interspace: All apparatus diminished the amount of flexion occurring at this level in both the erect and slumped positions. The experimental brace not only prevented motion, but maintained some extension of this joint in both the erect and the slumped positions.

At the fourth lumbar interspace: The same tendency to limit flexion was apparent when all types of apparatus were worn. However, the effects at this level seem inconsistent,

FIG. 20-C

FIG. 20-D

Fig. 20-C: When the subject is sitting erect, the lower straps are snug but not excessively taut. Their tension has not changed materially from that in the standing position because their points of attachment to the brace are at the axes of rotation of the hip joints. Furthermore their position is such that they fall into the inguinal folds when the subject is sitting.

Fig. 20-D: When the subject attempts to slump as is shown here, it is apparent that the backward rotation of the pelvis and the lumbar flexion which ordinarily accompanies this movement is largely eliminated. When the subject's position here is compared with that in Fig. 20-C, it is apparent that little change in position of the pelvis and lower trunk has occurred.

in some instances, when compared with those at the interspace below, notably with the reinforced Taylor brace and with the plaster-of-Paris jacket. This is probably the result of displacement of the skin in the proximity of the wires with resultant discomfort. This was a variable which was difficult to control. The experimental brace at this level, as at the one below, maintained a position of extension with the subject erect, but with slumping the interspace moved through a considerable arc of motion to just beyond neutral.

At the third lumbar interspace: As might be anticipated, all apparatus were effective, tending to maintain a position of extension with the exceptions of the Williams brace, which permitted slight flexion during slumping, and the Jewett brace, which permitted slight flexion during the erect sitting position. With several pieces of apparatus extension increased at this level during slumping. This effect was *most* noticeable with the rigid Taylor brace which was observed to cause considerable localized pressure at this level as the subject assumed the slumped position. In spite of the variable effects noted in this

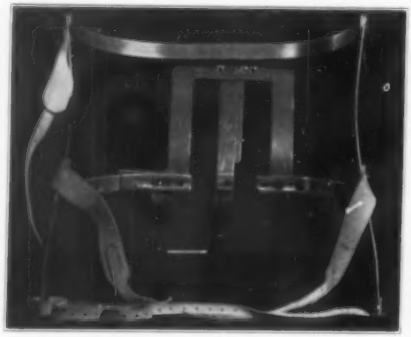

FIG. 21

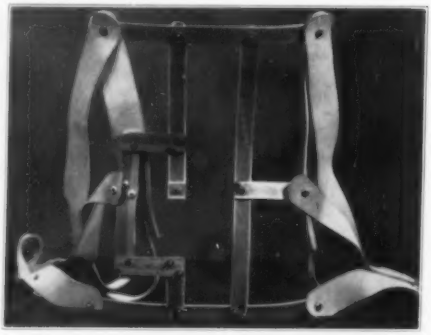

FIG. 22

Fig. 21: Anterior view of the experimental brace modified for testing with Kirschner-wire makers. The lower crossbar has been cut away over the left posterior superior iliac spine and the mid-line. The defect has been bridged by a rectangular member bent posteriorly in such a fashion that contact is made with the body only at the level of the crossbar. Slots cut in the crossbar allow adjustment of the width of the gaps through which the wires move.

Fig. 22: Posterior view of the Goldthwait brace after being modified for use with Kirschner-wire markers. The left projection and the middle segment of the middle crossbar and a short segment of the left vertical upright have been removed. A C-shaped member which does not contact the surface of the body has been added to restore rigidity and to furnish a point for the attachment of the left middle strap.

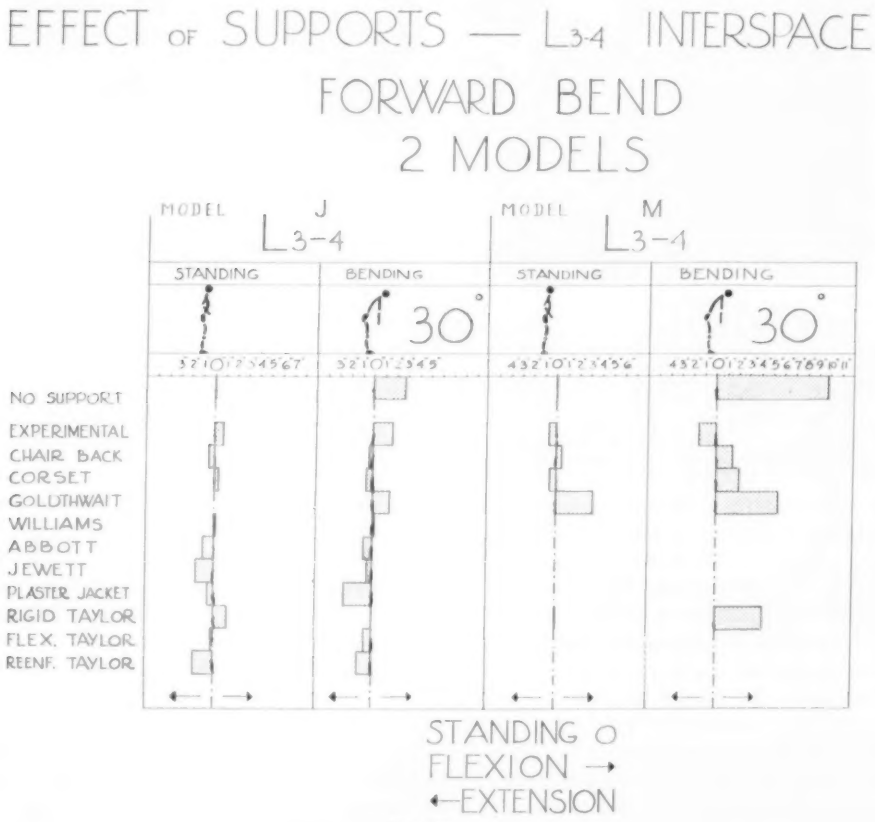

FIG. 23

Fig. 23: Effect of various back supports on the fifth lumbar interspace in the standing position and in 30 degrees of forward bending. The zero line for each subject represents the angle formed between the wires in the spinous process of the fifth lumbar vertebra and in the left posterior superior iliac spine with the subject in the standing position without support. The horizontal bars extending to the right or left from the zero line represent the changes in this angle due to bending without supports (first horizontal bar) and due to standing and bending while wearing various types of support (other bars). All values represent averages based on four to eight determinations.

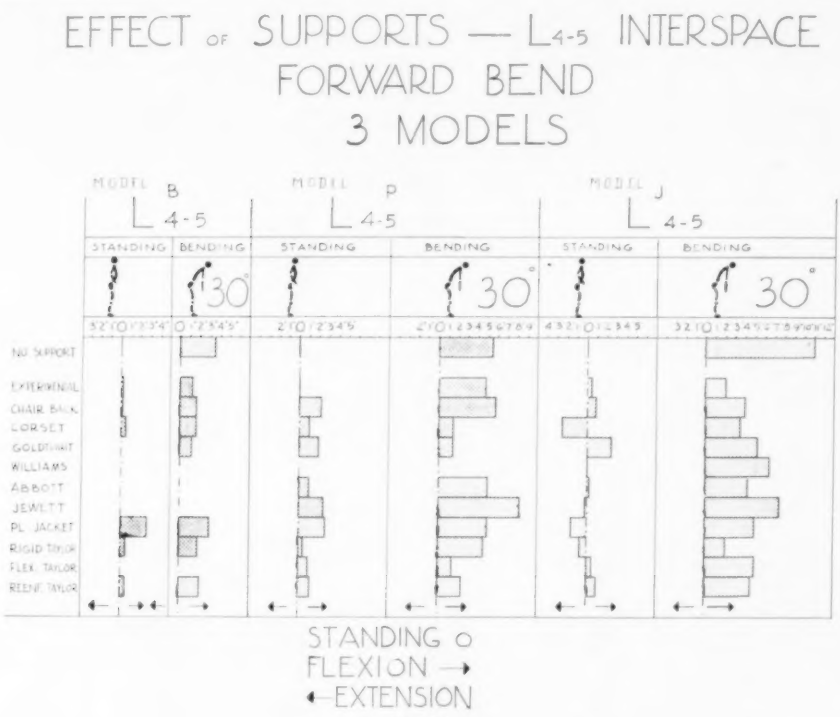

FIG. 24

Effect of back supports on the fourth lumbar interspace in the standing position and in 30 degrees of forward bending. The zero line for each subject represents the angle formed by the Kirschner-wire markers in the spinous processes of the fourth and the fifth lumbar vertebrae when the subject was in the standing position without a support. The horizontal bars extending to the left and right from the zero lines represent the changes in this angle due to bending without support (first horizontal bar) and due to standing and bending while wearing various types of support (other bars).

experiment, the experimental brace seemed to limit flexion and to maintain a position of extension more consistently than the other apparatus tested.

Although a study of lateral bending was not made, it was observed that the experimental brace appeared to restrict this movement more efficiently than the others. The extension of the lateral uprights downward to the greater trochanters was largely responsible for this increased effectiveness (Fig. 28). Patients fitted with this support frequently remarked that it prevented side bending.

Pressure Tests

A comparison of the forces developed by the different types of apparatus may be seen in Figure 29. As noted previously, it proved impossible to adjust the gauges on the different supports at exactly the same level on the back and to adjust the forces exerted by all types of apparatus so that they were the same as in the initial standing position in each test. However, since the significant point with regard to the force developed by a back support used for immobilization is the rapidity with which the force increases during

the act of forward bending, the values obtained are at least an indication of the comparative efficiency of the various supports. Interestingly enough, the speed at which the force increased was not necessarily related to the initial pressure between the brace and the back. This rather unexpected finding was apparently related to differences in the subjects' spinal flexion patterns and to differences in the mode of action of the apparatus.

Although the results of these experiments do not show clear-cut superiority of any one support as regards force produced against the low back, it seems fair to say that the experimental brace produced relatively large forces at the lumbosacral levels more consistently

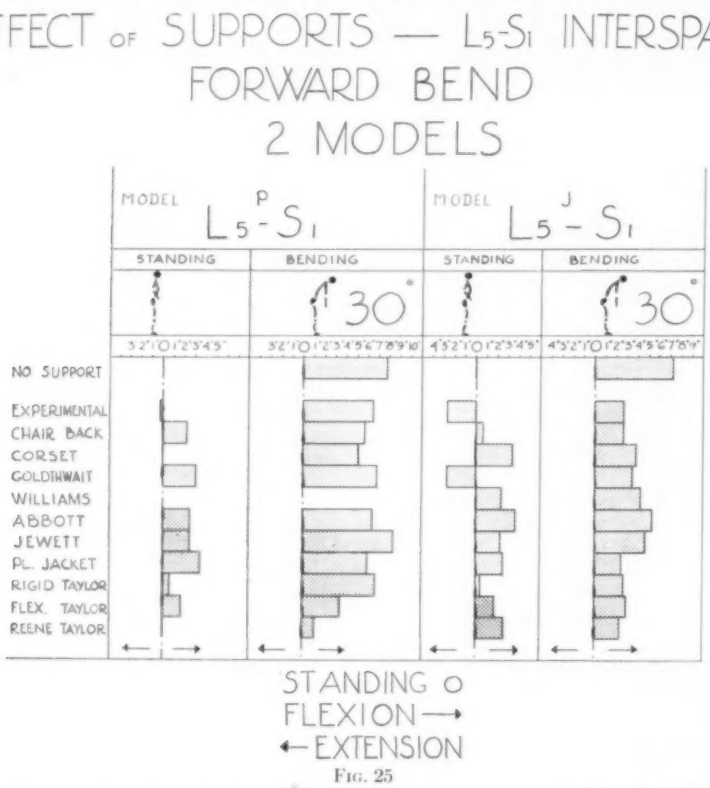

FIG. 25

Effect of back supports on the third lumbar interspace in the standing position and in 30 degrees of forward bending. See legends for Figs. 23 and 24 for explanation. Kirschner-wire markers in this instance were inserted in the spinous processes of the third and fourth lumbar vertebrae.

than the other supports tested. On these four subjects it excelled at 15 degrees of forward bending in one, at 30 degrees in two, and at 45 degrees in three. As regards the rapidity of build-up of force during forward bending, the performance of the experimental brace was also superior. Between 0 degrees and 15 degrees of forward bending, it excelled in only one instance (subject B), but between 15 degrees and 30 degrees its force build-up was greatest in three subjects (P, H, and B).

The reinforced Taylor brace, which was one of the more effective supports, did not produce very large forces in at least three of the subjects.

Clinical Trial of the Experimental Brace

Up to this time the experimental brace has been used on about 100 patients. In the majority of instances it was prescribed as postoperative immobilization after spine fusion

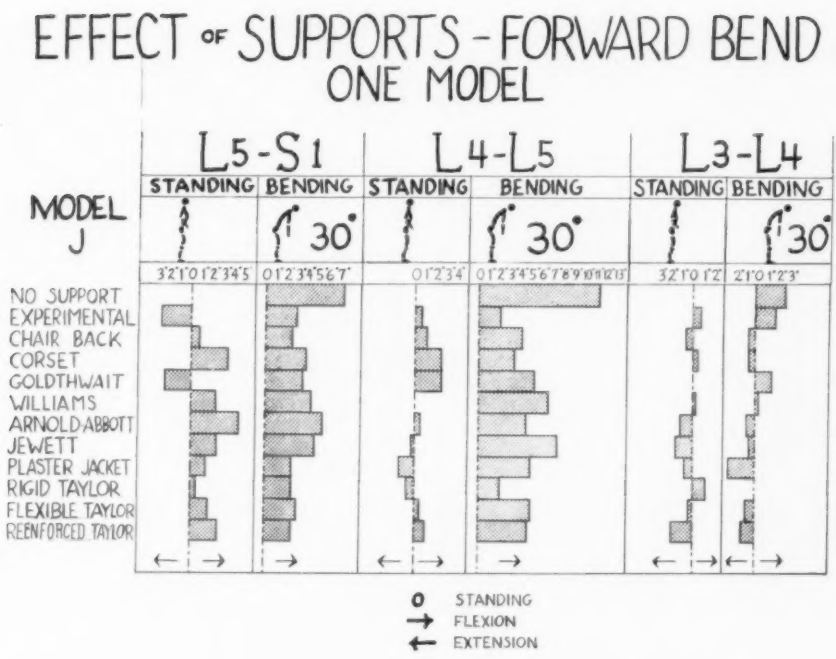

FIG. 26

Effect of back supports in the standing position and in 30 degrees of forward bending on the lower three lumbar interspaces in *one model*. The zero line for each interspace represents the angle formed by successive pairs of Kirschner-wire markers in the spinous processes of the third, fourth, and fifth lumbar vertebrae and in the left posterior superior iliac spine when the subject was in the standing position without support. See legends for Figs. 23 and 24 for further explanation. Note variable effects at adjacent interspaces. In the standing position extension of the fifth and flexion of the fourth lumbar interspace and vice versa occurs with various types of apparatus.

performed for low-back disabilities. It has not been in use for a sufficient length of time to draw any conclusions as to its effectiveness. Only impressions can be reported at this time.

It has been prescribed by several doctors not connected with this project, and it has been satisfactory to both the doctor and the patient with but few exceptions.

The principal complaints have concerned (1) the prominence of the trochanteric pads, objected to by women particularly, (2) the pressure over the ribs at the upper end of the lateral uprights, (3) the prominence of the upper crossbar beneath the clothing, and (4) the discomfort from the large abdominal pad in the epigastric region and at the xiphoid process.

These objections have been eliminated almost without exception by more careful fitting of the apparatus.

After spine fusion, an occasional patient has complained of undue pressure over the tender operative scar. This difficulty has been obviated by bending the crossbar to reduce or eliminate pressure where the bar crossed the tender area.

Two patients who had used other braces in the past volunteered that this apparatus gave them better support. A salesman, who customarily drove between Boston and Chicago in the course of his work, had been forced to take to the train in order to travel in a recumbent position. He was able to resume driving when he had been fitted with the experimental brace, and he has continued to drive his car for eight months.

The true measure of the effectiveness of this support as immobilization after spine fusion will depend upon the incidence of pseudarthrosis when this brace is used as com-

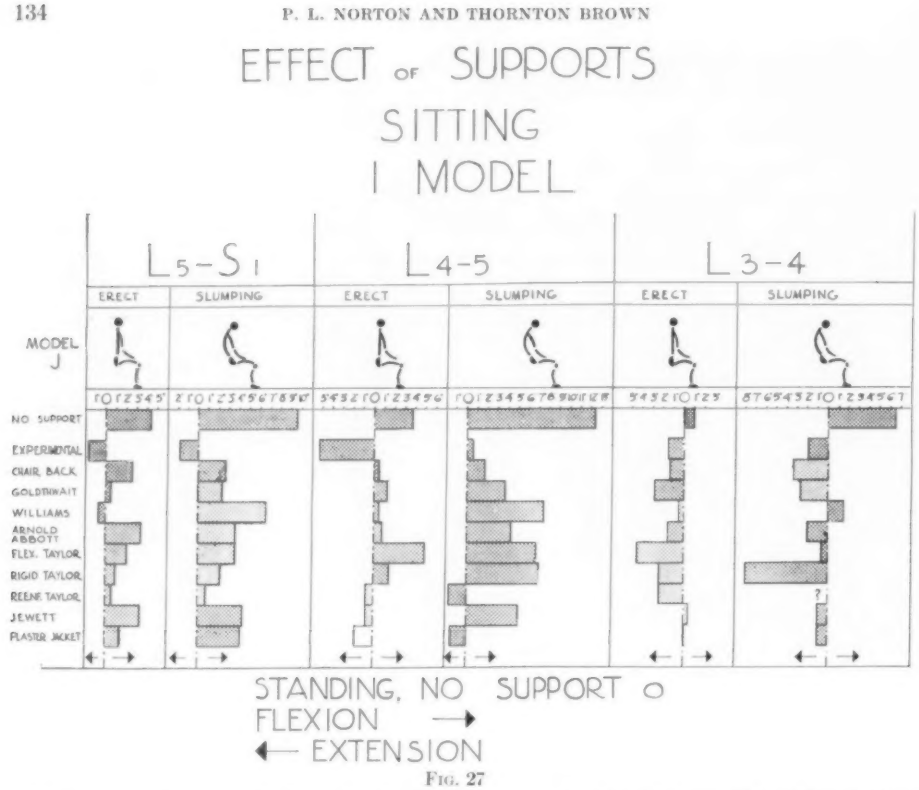

FIG. 27

Effects of back supports on the lower three lumbar interspaces when the subject was in the sitting position. The zero line for each interspace represents the angle formed by the successive pairs of Kirschner-wire markers in the spinous processes of the third, fourth, and fifth lumbar vertebrae and in the left posterior superior iliac spine when the subject was in the standing position without support. The horizontal bars extending to the left and right from these zero lines represent the changes in these angles due to sitting erect and sitting in the slumped position without support (first bar) and with various types of apparatus (other bars).

pared to the incidence of this complication when other supports are employed. No such comparison is possible at this time. One instance of failure of fusion after arthrodesis of the fourth lumbar interspace and the use of the experimental brace has been reported so far.

Of some interest was a patient convalescing from an attack of acute low-back pain with radiation of pain down the posterior aspect of the right lower extremity to the calf. He preferred a reinforced corset to the experimental brace, stating that he felt more comfortable in the corset although the brace did restrict his back motions more effectively. Comparative standing and bending roentgenograms showed that the brace caused him to stand with the lumbosacral joint in extension while the corset produced slight flexion at this interspace (Fig. 30). Although the location of this patient's lesion was not established, it seems entirely possible that the extension of the fifth lumbar interspace associated with wearing the brace was less favorable than the flexion produced by the corset in this presumed intervertebral disc lesion.

DISCUSSION

In this preliminary report the data are inadequate, and there were too many technical faults to permit final conclusions as to the immobilizing efficiency of back braces. Nonetheless, points of considerable interest have been raised about normal lumbosacral motion and the effects of braces on it.

FIG. 28-A

FIG. 28-B

Comparison of side bending in (Fig. 28-A) the experimental brace and (Fig. 28-B) in the Goldthwait brace. Failure of the latter to grip the pelvis is obvious.

Even in the few subjects studied, a wide variation of motion at the lower three interspaces was found. This varied not only as regards the range of movement, but also with respect to progression of flexion during the course of forward bending. For example, one subject with tight hamstrings and poor ability to bend forward exhibited much more flexion in his lower lumbar articulations than a subject with loose posterior structures who could touch the floor. Again, some subjects appeared to expend all of the available range of flexion in their lumbosacral joints during the first 30 degrees of trunk bending, while in others, flexion at this level occurred in a more gradual manner. The impression was gained that definite flexion patterns exist which may well be of some clinical significance. For instance, it would seem reasonable to assume in the absence of back symptoms that the subject with the least lumbar motion during forward bending would be less susceptible to low-back strain or to wear and tear changes than the others. Similarly, the indications for spine fusion after disc surgery and the incidence of pseudarthrosis after fusion might well differ in these two types.

Sitting, even if erect, was found to be associated with substantial flexion of the lower two lumbar interspaces. In fact, flexion was greater at the fourth lumbar interspace in the slumped position than it was when the same subject was standing in maximum forward flexion. If the object of treatment is to immobilize the lumbosacral spine, either sitting must be avoided or the apparatus employed for immobilization must be effective in this position.

The action of various back supports undoubtedly varies according to the lumbar flexion pattern. However, these studies have not progressed sufficiently to elucidate this point. In one subject with minimal motion of the lower lumbar interspaces during trunk flexion, comparatively little force was developed by the various supports at the lumbosacral level.

Close observation of the action of long back supports during forward bending and

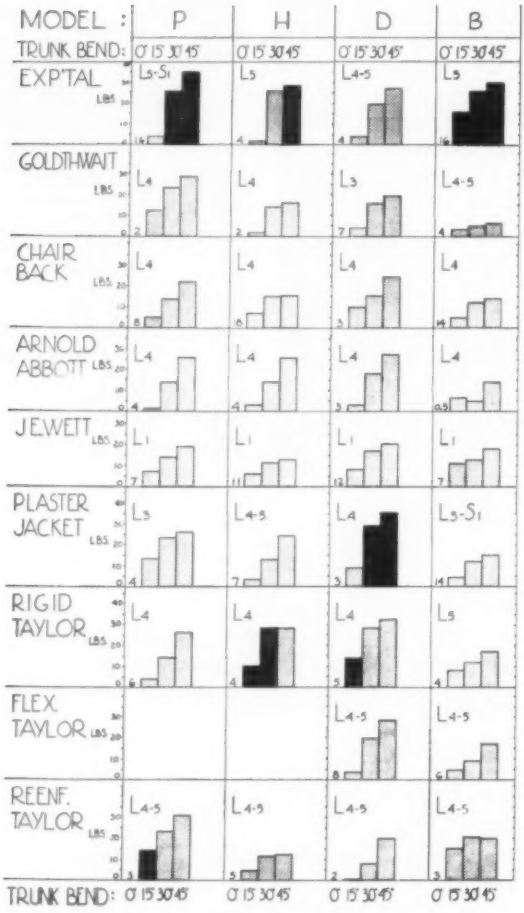

FIG. 29

Comparison of forces produced against the low back in four subjects by various types of apparatus. The vertical columns represent the increase of the force recorded when the subjects were bending forward to 15 degrees, 30 degrees, and 45 degrees. The black columns represent the maximum force developed on each subject for each of the three positions. The forces exerted by each apparatus in the standing position are indicated by the numerals in the lower left-hand corner of each square, while the level at which the force was exerted is indicated in the upper left-hand corner. For technical reasons it proved impossible to adjust the level and the initial force so that they were truly comparable.

sitting indicates that the concentration of force from the brace is usually located at or near the thoracolumbar junction, much too high to immobilize the lower lumbar segments. In fact, lumbosacral flexion was actually greater in some subjects when a long brace was worn than without it.

None of the braces tested did more than limit interspace flexion. Actual immobilization never occurred. In the standing position some caused interspace flexion, others interspace extension. Irrespective of this, some amount of flexion invariably accompanied for-

ward bending. The effect of most braces was to reduce the arc of motion in flexion. In several instances, the arc of motion was shifted toward the extension side of neutral. In these studies no support has shown clearly consistent effects on all subjects.

In the same subjects opposite effects were noted at adjacent interspaces with extension at the fifth lumbar interspace and flexion at the fourth lumbar interspace or vice versa. No explanation for this peculiar behavior was found.

The effectiveness of the supports with respect to immobilization seemed to be related

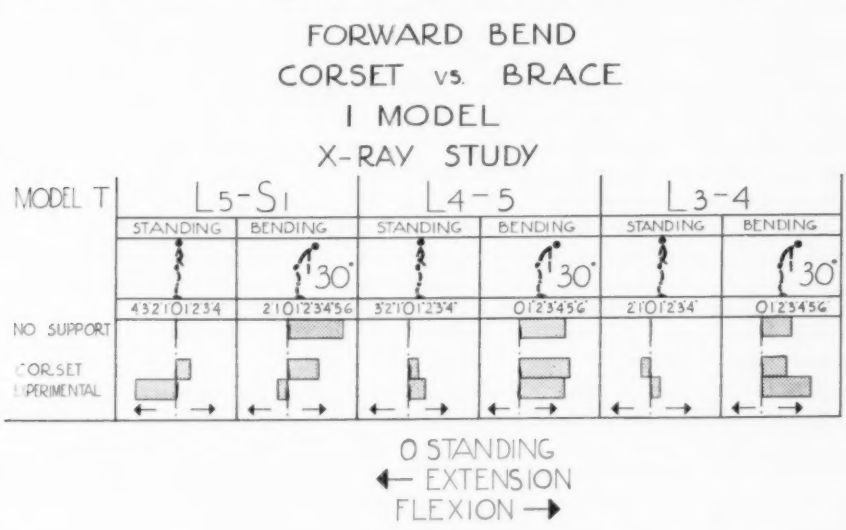

FIG. 30

Effect of the corset and the experimental brace on a patient, convalescing from an attack of low-back pain and sciatica, during standing, and in 30 degrees of forward bending (see legend for Fig. 23). In the standing position the brace caused appreciable extension at the fifth lumbar interspace and slight flexion at the two interspaces above, while the corset produced slight flexion at the lumbosacral and fourth lumbar interspaces but slight extension at the top articulation. At 30 degrees of forward bending, the brace allowed some flexion at the fifth lumbar interspace but this occurred on the extension side of neutral. At the articulations above, flexion equal to or in excess of that occurring without any support was recorded. With the corset, on the other hand, at the fifth lumbar interspace motion was sharply limited, but it occurred on the flexion side of neutral. At the joints above this, motion roughly comparable to that occurring with the brace was noted although within a different arc.

In this case neither support significantly affected the two upper interspaces. At the lumbosacral joint the brace maintained an extended position without complete immobilization while the corset reduced the lumbosacral angle and effectively limited motion.

more to the discomfort produced than to the magnitude of force developed between the apparatus and the back. In none of the supports tested did the force produced over the paraspinal muscles approach an uncomfortable degree during the early phases of forward bending. The current practice of employing paraspinal uprights to immobilize the lumbosacral spine would seem to be incorrect for two reasons: the force is not localized at the points desired and does not produce the necessary discomfort to cause immobilization. The action of a low-back brace should be to remind the wearer promptly that he should limit spinal motion by muscular action. It seems highly unlikely that any device applied to the exterior of the body can effectively splint the lumbosacral region.

With these considerations in mind, a brace is presented, which, so far as we have been able to ascertain, embodies a principle not tried previously. By replacing the paraspinal uprights with lateral uprights which extend downward to the greater trochanters and by applying force to the lumbosacral region by means of a single crossbar, two goals are achieved. First, the force is kept localized over bony prominences so that prompt and

somewhat uncomfortable pressure accompanies forward bending or slumping in the sitting position. Second, a low point of attachment for the lower straps of the abdominal pad gives good counterpressure at the lower end of the brace without impeding sitting in the erect position. Incidentally, side bending is quite effectively blocked by the lateral uprights.

The performance of this brace has been superior in restricting flexion of the lower lumbar interspaces in the sitting position. During standing and forward bending its effect has been variable. While usually effective at the fourth lumbar interspace, its action at the lumbosacral joint has been to shift the arc of motion toward extension rather than substantially to reduce interspace flexion. In its brief clinical trial, the performance of the experimental brace has been encouraging. The principles governing its design appear to be sound, although further refinements may be indicated.

On the basis of these studies it is suggested that back supports could well be prescribed and probably fitted with more accuracy if consideration is given to the action desired. Certainly after lumbosacral fusion, particularly if a locking type of graft is used, the postoperative brace should produce a position of extension of the involved region of the spine. In the case of a lordotic spine with postural backache the opposite effect is desirable. Furthermore, it is our impression that in the treatment of low-back pain a careful study of the history will often reveal whether flexion or extension seems to be the more comfortable position. This being the case, prescription of a suitable back support should not be purely empirical.

Since the effect of a brace is not always predictable, it would seem advisable to test the effect of the brace once fitted by suitable standing and bending roentgenograms.

This progress report has only scratched the surface of the problem of movement of the lumbar spine and how to modify it. Further study with improved techniques and many more subjects, both those with and those without back symptoms, would seem warranted.

NOTE: The authors wish to express their appreciation to Dr. Joseph S. Barr, John Ball and Buckminster Brown Professor of Orthopaedic Surgery, Harvard Medical School and Chief of Orthopaedic Service of the Massachusetts General Hospital, for his general supervision of this investigation. They also wish to thank Robert L. Hansen, Ph.D., Associate Professor of Civil Engineering at the Massachusetts Institute of Technology, Y. C. Loh, Ph.D., formerly of that department, and Eugene Murphy, Ph.D., Chief of Prosthetics and Sensory Aids Division of the Veterans Administration, for their helpful advice on many of the engineering problems which were encountered.

The technical assistance of John Menge and Thomas Broderick, Jr., M.D., and of the brace makers Karl Buschenfeldt and William Murphy is also gratefully acknowledged.

Mary Cahouet was of great help in the preparation of the manuscript. Donald Withee, photographer at the Massachusetts General Hospital, cooperated in the preparation of the illustrations.

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DISCUSSION

DR. PAUL C. WILLIAMS, DALLAS, TEXAS: Dr. Norton and Dr. Brown are to be complimented on undertaking this complex problem. As yet no brace has been designed that will function with the same effectiveness on all individuals. The very loose-jointed person and the very firm-jointed person need two entirely different pieces of equipment for immobilization of the lower spine. The use of the Kirschner-wire markers was quite a novel idea. I am inclined to believe that there might have been a pain factor which could have altered function, having in mind the fact that we voluntarily splint our lower backs in the presence of pain. The ap-

paratus used in determining pressure was of such bulk that it could have altered the effectiveness of the braces somewhat, as well as the mobility of the subjects.

The problem of external fixation of the lower spine, as I see it, is that of trying to immobilize a flexible skeletal rod which is attached at each end to a skeletal ring; namely, the thorax and the pelvis. It is reasonable to believe that, in order to accomplish this, a brace must have encircling bands which provide a good grip on both rings and which are then joined by rigid bars. In my opinion, these principles have been best carried out in the Steindler brace, although there are other models developed along the same lines which have been just about as effective. The principal criticism I have of the experimental brace is that it fails to take a firm enough grip on the pelvis to prevent its posterior rotation. The level of the lower horizontal band is too high to prevent extension of the lumbosacral spine. It is located slightly below the axis of anteroposterior flexion of the lumbar spine. In the average person this axis of rotation is located at about the fourth lumbar vertebra, and the lower transverse band of the experimental brace rests just over the spinous process of the fifth lumbar vertebra. I suggest that a third transverse band be added at the level of the sacrococcygeal junction.

I want to thank Dr. Norton and Dr. Brown for forwarding their paper to me early enough so that I had time to make up a model of the brace and try it out. I found it quite effective in preventing flexion of the lumbosacral spine and, contrary to my preconceived idea from reading the paper, it was far more comfortable than I had expected it would be. All these criticisms are intended to be constructive, and I sincerely hope that the authors will continue with this investigation. They will have contributed a great deal if they can rid us of the many ineffective braces which I am inclined to speak of as "nuisance" braces. Such braces push the patient in in one place and push him out in another, but their only effectiveness lies in the fact that the patient eventually gives up and decides to hold still.

DR. EUGENE MURPHEY, NEW YORK, N. Y.: It is a pleasure to discuss this stimulating paper. Rehabilitation of a patient with a spinal anomaly requires a brace that will provide the necessary immobilization of the involved part yet permit maximum function of the remainder of the body, so that the back will be free to move over as great a length as possible. The authors show that some braces practically reverse the process, tending to stringently limit gross torso movement yet not adequately immobilizing the involved segments of the spine. A normal subject, uninhibited by pain, was able to move the critical vertebrae in bending forward against the brace even more than he did bending forward without a brace; this was possible because the pressure of the brace exerted a force of its own.

This analysis of many types of braces, undertaken with the aid of Professor Hansen and his engineering colleagues at the Massachusetts Institute of Technology, has culminated in an increased understanding of the action of the forces exerted. The pressure shoes clamped to the brace bars were rather clumsy but the best means available. The electrical strain gauges permitted accurate measurement of forces under nearly isometric conditions. Fortunately for further experimentaton the Franklin Institute Laboratories have recently developed for the Quartermaster Corps new electrical capacitance gauges, which are about the size of a coin, to measure pressure between the human body and an adjacent surface[a]. These "Filpips", as they are called, are currently being used to measure pressure between an amputation stump and the socket of an artificial limb. They should permit more accurate determinations of the support offered by a brace, corset, restraining strap, or plaster cast. The small size of the "Filpip" would eliminate the need for slots or rebuilding of the appliance and would cause only negligible change in the pressure occurring in the absence of a gauge.

The experimental brace seems sound from an engineering standpoint. During undesirable movements, it applies the three-point bracing principle; a localized and uncomfortable pressure is caused in the region of the low back where it should be most effective and counterpressures are exerted by long lever arms. The two vertical bars are thickest from front to rear, giving maximum strength and stiffness in the plane subject to greatest bending loads. The lowest strap is swivelled so that it is substantially in line with the anatomical axis, and the strap follows in a natural fold of the body during sitting.

The authors suggest that discomfort from a brace serves as a reminder to the patient to brace himself by pulling back to a correct (and comfortable) position with his own muscles, which are intact in these cases. Perhaps the extreme in simplicity of brace design would be merely a corset steel and a thumb tack!

The striking variations between braces and the differences between individuals suggest further adaptation to this field of the prescription team which has been so effective in solving other prosthetic and orthopaedic appliance problems[b]. The doctor, the brace fitter, the therapist, plus any other necessary consultants, can select and later evaluate the particular appliance logically needed for the individual patient. This paper should stimulate the thinking of the entire team.

[a] FRANK, W. E., and GIBSON, R. J.: A New Pressure-Sensing Instrument. J. Franklin Institute, **238:** 21–30, 1954.

[b] BECHTOL, C. O.: The Prosthetics Clinic Team. Artificial Limbs, **1:** 9–14, 1954.

DR. BROWN (closing): I should like to thank the discussors for their thoughtful criticisms. Dr. Williams has pointed out deficiencies in our techniques of which we are well aware. I think any discussor who will

(*Continued on page 220*)

Effects of Strontium and Fluoride on the Repair of Unreduced Humeral Fractures in the Adult Rat

BY WILLIAM B. SAVCHUCK, D.D.S., PH.D., BETHESDA, MARYLAND

From the National Institute of Dental Research, National Institutes of Health, Public Health Service, United States Department of Health, Education, and Welfare, Bethesda

Strontium and fluoride are both avidly taken up by the osseous tissues. Both strontium [9] and fluoride [5] can be accommodated in the bone-crystal lattice, and since the two ions are of opposite charge, theoretically they should not compete for the same positions in the crystal structure. The literature suggests that strontium is well retained by the skeletal system and that it may possess certain advantages over calcium in remineralization of the depleted human skeleton [14]. Like strontium [8], fluoride also is readily deposited in the skeleton where it is so fixed that its elimination is limited [13].

Because of the affinity of bone for both strontium and fluoride, it seemed interesting to determine what effect a combination of the two ions in non-toxic concentration would exert upon the mineralizing phase of bone repair. In this work the unreduced fractured left humerus of the adult male rat was used as a test bone to study the influence on bone repair of strontium and fluoride, alone and in combination. Some aspects of the healing of this type of fracture were studied (1) autoradiographically, (2) chemically, (3) physically, and (4) histologically.

EXPERIMENTAL METHODS AND FINDINGS

1. Gross Autoradiographic Study of Fracture Healing by Use of Sr ^{89}

Theoretically, the stage at which fracture callus exhibits its maximum affinity for strontium may also be that at which strontium exerts its maximum effect on healing. The present study was designed to reveal autoradiographically at what stage of repair a single dose of strontium would show the greatest uptake in the fracture area. The relative intensities of strontium uptake by the callus at various intervals after fracture were estimated on the basis of the intensity of strontium uptake at the proximal epiphysis of the fractured bone *.

A group of white male rats weighing about 200 grams each were obtained from the National Institutes of Health. The animals received Purina Laboratory Chow and distilled water. After attaining a body weight of 350 grams, each rat was anaesthetized and the left humerus was fractured by being bent over the edge of a fixed bar. A total of twelve rats was chosen for this experiment on the basis of uniformity of angulation and overriding of the fragments as observed roentgenographically. Pairs of rats were sacrificed at successive two-week intervals following fracture. Each animal received intraperitoneally fifty milligrams of irradiated strontium ** two days before sacrifice.

Distribution of the strontium throughout the fracture region seemed most intensive and extensive at four weeks after fracture (Figs. 1-A, 1-B, and 2-B). Beginning at ten weeks the autoradiograms showed a noticeably reduced uptake within the fracture area, the strontium localizing about the cortex and the interfragmentary plane becoming almost completely obliterated. The gross autoradiographic differences at four and at

* Thus, if the Sr^{89} uptakes at the proximal epiphyses of two adult humeri appeared to be of equal intensity, variation in uptake within the respective fracture regions was regarded as a true difference rather than one attributable to other factors, such as difference in development time of each film.

** The Sr^{89} used in these studies was supplied as thirty-three gram units of strontium nitrate, the activity of which upon receipt was approximately 1.5 millicuries. All Sr^{89} was administered within the first half-life after removal from the uranium pile.

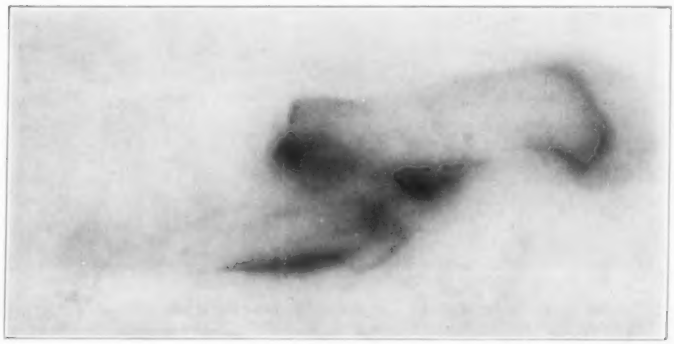

FIG. 1-A

Figs. 1-A and 1-B: Autoradiograms of sagittal mid-sections of fractured, unreduced humeri of adult rats. Each animal had received Sr^{89} two days before sacrifice.

Fig. 1-A: Autoradiogram (× 3.7) of humerus two weeks after fracture. Healing is in the early stages of ossification, as is evident from the beginnings of mineralization in the interfragmentary space. The active role of the periosteum in bone repair is indicated by its uptake of Sr^{89}.

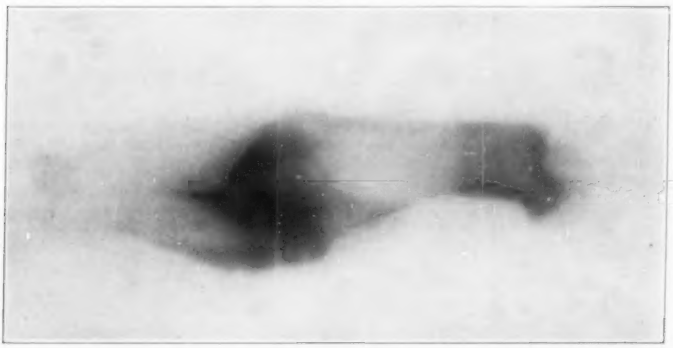

FIG. 1-B

Autoradiogram (× 3.4) four weeks after fracture. Note the extent of the mineralizing area around the displaced ends of the fracture and the decreasing order of intensity of the strontium localized in the fracture region, the proximal epiphysis, and the distal third of the bone. The greater strontium uptake is about the concavity. The fracture clefts are almost indiscernible, partly because of obliteration caused by the high energy of the beta particles associated with the heavy Sr^{89} uptake by the callus.

ten weeks were less pronounced than the corresponding histological changes observed in decalcified sections of the same bones. Histologically, the new bone at ten weeks was more dense and less cellular—that is, distinctly more mature than at four weeks—and marrow was channeled through among the trabeculae. The bulk of cartilage uniting the fragments at four weeks was replaced by a bony trabecular network at ten weeks.

Probably the most revealing autoradiogram in this series was that of a mid-sagittal section of a humerus six weeks after fracture (Fig. 2-B). The interfragmentary zone seems to be interposed between mineralizing bone on each side. The heavier uptake is about the concavity of this unreduced fracture. Another sagittal section through the fracture region of this same bone (Fig. 2-C) shows the histological structures involved. The presence of newly forming reparative bone probably accounts for the marked strontium deposition in the fracture area evidenced in the autoradiogram. The autoradiographic findings in this study are in accord with the reported histological observation of the centripetal progression of ossification in the callus [15].

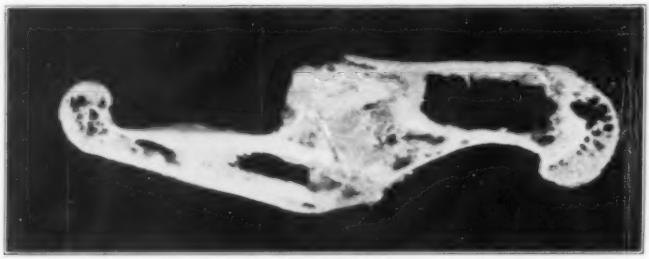

FIG. 2-A

Gross mid-sagittal section (× 3.4) of a fractured, unreduced adult rat humerus after six weeks of healing.

FIG. 2-B

Autoradiogram (× 3.4) of section shown in Fig. 2-A. Sr^{89} was given two days before sacrifice. Note the heavier deposition of strontium about the concavity and the pattern of mineralization, advancing toward the interfragmentary space.

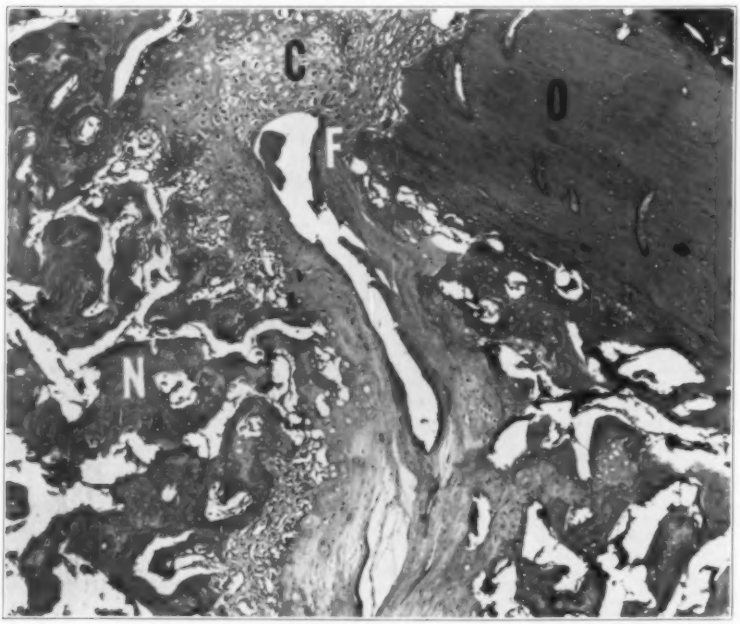

FIG. 2-C

Sagittal section (× 73), decalcified and stained with hematoxylin and eosin, from another portion of the same specimen. Note the distinct fracture cleft surrounded by reparative tissues. *F*, fibrous elements; *C*, cartilage; *N*, newly formed bone; *O*, original compact bone.

TABLE I

UPTAKES OF STRONTIUM BY THE HUMERI AND FEMORA OF ADULT RATS

Group, Week after Fracture	Bone	Regimen*	Average Ash Content (Per cent) **	Average Ash Content (Milligrams)	Experimentally Acquired Sr Contained in Ashed Bone *** (Per cent)	Experimentally Acquired Sr Contained in Ashed Bone *** (Micrograms)	Ratio of Per Cent Sr Uptakes by Fractured: Sound Humeri	Increase in Uptake of Sr by Fractured Humerus † (Micrograms)
1 Fourth	Fractured humerus	control	62.0	206	0.41 a	0.45 b 883	2.2	531
		fluoride	61.3	212	(0.28)c	(0.36)d (685)	(2.4)	(445)
	Sound humerus	control	64.3	178	0.18 a	0.21 b 352		
		fluoride	64.4	173	(0.13)c	(0.14)d (240)		
	Femora	control	65.2	734	0.15 a	0.19 b 1237		
		fluoride	64.1	707	(0.11)c	(0.13)d (876)		
2 Eighth	Fractured humerus	control	64.7	207	0.32 e	0.37 f 705	2.2	435
		fluoride	64.0	208	0.30 g	0.31 h 638	2.1	393
	Sound humerus	control	65.5	175	0.15 e	0.16 f 270		
		fluoride	64.4	172	0.13 g	0.16 h 245		
	Femora	control	65.2	726	0.15 e	0.14 f 1068		
		fluoride	64.7	686	0.14 g	0.13 h 910		
3 Twelfth	Fractured humerus	control	66.5	220	0.23 i	0.20 j 474	1.6	214
		fluoride	66.2	229	0.17 k	0.18 m 400	1.7	186
	Sound humerus	control	66.6	194	0.13 i	0.14 j 260		
		fluoride	66.9	201	0.10 k	0.11 m 214		
	Femora	control	66.2	820	0.11 i	0.14 j 1006		
		fluoride	66.3	814	0.09 k	0.09 m 748		

* Sr^{89} injected on the first, third, fifth, and seventh days, and sodium chloride (control) or sodium fluoride on the second, fourth, sixth, and eighth days of the regimen. Values within parentheses represent the pair of fluoride-injected rats which died after injection on the fourth day of the regimen. One rat (d) of this pair had a relatively large fracture callus.

** Per cent of mineral matter in unashed, dry, defatted bones.

*** The strontium acquired pre-experimentally, presumably of the order of 0.02 per cent (based on calculations of human bone ash[6]), was not determined and is disregarded in this table. Percentages are calculated on an ash basis and are expressed for the individual rats, each identified by a small letter. The total strontium content in micrograms is assumed to be unaffected by ashing.

† The absolute difference (in micrograms) between the uptakes of the fractured and sound humeri, that is, essentially the strontium uptake by the fracture callus.

2. Effect of Fluoride on Deposition of Strontium in the Fracture Callus

A pertinent question evolving from the introductory remarks is whether fluoride enhances or inhibits the retention of strontium in ossifying fracture callus. The following study upon a limited number of selected animals embodies a preliminary approach to the problem.

The left humerus was fractured in a group of adult male white rats from the National Institutes of Health colony when the individual animals attained a body weight of 350 grams. From this group twelve rats were selected whose unreduced fractures were considered to be of about the same grade roentgenographically. During the fourth week after fracture a group of four rats received intraperitoneal injections of fifteen milligrams of irradiated strontium on the first, third, fifth, and seventh days. On the second, fourth, sixth, and eighth days two rats were given injections of sodium fluoride, while the other

two rats, serving as controls, were given injections of saline. The group of four was sacrificed on the ninth day. This procedure was repeated during the eighth and twelfth weeks after fracture. Since the fluoride dose of 6.5 milligrams * proved fatal to the first pair of rats (Group 1) after the second injection of fluoride, this dose was reduced to 2.0 milligrams during the eighth and twelfth postfracture weeks.

The chemical determinations involved ashing the fat-free humeri and femora at 650 degrees centigrade. After dissolving of an ashed bone in a suitable volume of 3N hydrochloric acid, the activity of a one-milliliter aliquot in a glass planchet was measured with a mica window counter tube.

In Table I the percentage of strontium in the ashed bones of Groups 2 and 3 indicates that under the conditions of this experiment fluoride (in the given dosage) certainly did not increase, and may possibly have decreased, the acquisition of strontium by both the fractured and the normal bones. The percentage of strontium taken up by the unreduced fractured humerus was twice that deposited in the sound limb, except for a drop in this ratio toward the end of the repair period. A more reliable measure of the relative strontium uptakes of the fractured member at different periods is the total quantity deposited, measured in micrograms. On this basis, strontium acquired by the fractured humerus in excess of that deposited in the sound one was 50 per cent less in the twelfth week than in the eighth week after fracture. The corresponding decrease in the ash weight of the callus was only 20 per cent; thus if the difference in ash weights of the fractured and sound bones is attributed chiefly to the ash weight of the callus, the average callus ash weights for Groups 2 and 3 were thirty-four milligrams and twenty-seven milligrams respectively. This disparity (50 per cent as compared with 20 per cent) is only an apparent one, since the decrease in weight of the callus reflects the over-all reconstructive changes occurring during the last four weeks of the experiment, whereas the diminished strontium uptake indicates the affinity of the callus for strontium in the twelfth week only.

The distribution of fluoride among the several skeletal components of an individual rat appears to be approximately proportional to the mass of mineral salt in the various unfractured bones [13]. This uniformity of distribution indicates that in any normal skeleton the quantity of mineral salt in a particular bone is probably (perhaps indirectly) the major factor which determines its accumulation of fluoride. Presumably this is true for strontium as well, judging by the uniformity of uptake (percentage of Sr) of the femora and the sound humeri in individual animals (Table I). The values for the humeri are only slightly higher than those for the femora. The consistency in the amount of strontium contained in ashed rat femora and vertebrae has been noted by others [8].

On a sustained strontium intake the accumulation of strontium in the bones continues at a progressively diminishing rate [8]. In this respect it is interesting to note the relatively high uptake of but two of the four doses of Sr [89]. While the fourth-week controls received four injections of strontium, the pair which succumbed to an overdose of fluoride had received only the initial two injections. Disregarding the influence of fluoride on strontium deposition in Group 1, the inference is that the two final injections—that is, the third and fourth injections—of strontium failed to double the quantity of strontium acquired by the humeri and femora.

3. Influence of Strontium and Fluoride on Breaking Strength

Physical findings on excised bones offer a direct means of appraising the efficacy of a preoperative or postfracture regimen. In the remaining studies an attempt was made to correlate the intake of strontium and fluoride with the breaking strength or fracture resistance of excised sound and repaired bones. A histological study of the fracture callus

* The normality of one milliliter of solution containing either fifteen milligrams of strontium or 6.5 milligrams of fluoride is 0.34.

was made to correlate breaking strength with microscopic structure. Stable isotopes were used in these studies, since non-radioactive elements permit observation of uncomplicated long-range results of their continuous ingestion.

A. Technique of Measuring Breaking Strength and the Regain of Strength in the Fractured Humerus

Since a basic requirement in any fracture study is the objective evaluation of the extent of healing, it was felt that this condition could be met by comparing the breaking strengths of the repaired humeri of control and test animals. A special static-loading assembly (Fig. 3) was devised and tested for its consistency in measuring the comparative breaking strengths of small bones.

The bone is placed across two fixed knife edges. Wet specimens are dried with cleansing tissue immediately before testing. A four-liter, heavy-walled separatory funnel serves as a thirty-pound mercury reservoir from which the liquid is fed into a stainless-steel bucket. This container is suspended from the specimen by a chain, the uppermost link of which is knife-edged and rests on the previously marked mid-point of the segment being tested. After the bone fails, the bucket and contents are weighed. This technique may offer some advantages over previously reported methods [1,4,7,12], because of the simplicity of the apparatus: mercury is substituted for lead shot, it is not necessary to embed the ends of the bone in plaster-of-Paris, and wet as well as dry specimens may be tested.

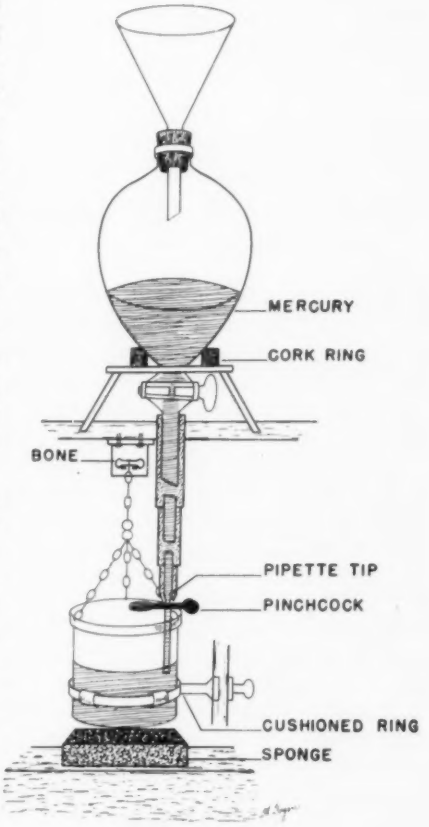

FIG. 3

Diagrammatic representation of static-loading assembly for measuring relative breaking strengths of small bones.

There are two empirically determined factors governing the magnitude of the failure load; these are the diameter of the pipette tip and the span between the knife edges. For the rat humerus it was found that a failure load of about twenty pounds delivered within one minute could be obtained with a fourteen-millimeter span and a pipette tip having an inner diameter of 2.5 millimeters at the orifice. The knife edges were accordingly fixed at this span by being soldered into an angle iron. In order to stabilize the humerus during the test a small notch was cut into one of the knife edges to seat the deltoid tuberosity. The notch was hollow-ground to produce a contacting edge without thickness.

As a precaution against the loss of mercury a cover was securely attached to the bucket and the lip was heavily sealed with paraffin. The cover was provided with an opening to admit the delivery tube and with a vent to facilitate pouring. The stopcock on the separatory funnel was securely fixed to prevent leakage.

In a series of preliminary trials several methods of bone preparation were compared on the basis of the degree of correspondence between the right and left bones of a pair. These screening procedures involved testing pairs of bones, each pair having been pre-

TABLE II

AVERAGE RELATIVE BREAKING STRENGTHS OF ADULT RAT TIBIAE

Regimen	No. of Rats	Average Breaking Strength of Pair of Tibiae (*Pounds*)	Average Absolute Deviation of Breaking Strength of Either Tibia from the Average Breaking Strength of the Pair (*Pounds*)
Fluoride	14	23.3 ± 2.2*	0.9
Strontium and fluoride	16	21.4 ± 1.4	0.4
Strontium	16	21.4 ± 2.3	0.6
Control	12	21.9 ± 1.3	0.5
Total	58	22.0 ± 2.0	0.6

* Mean ± standard deviation.

pared by one of the following methods: (a) recent excision, (b) autoclaving before removal of soft tissue, (c) oven-drying at 110 degrees centigrade, (d) incubation in saline solution, (e) defatting and drying, or (f) preservation in a 10 per cent neutral formalin solution. Results obtained with formalin-fixed bones appeared to be at least as consistent as those from any of the other procedures and, since formalin fixation permitted subsequent histological study, it seemed to be the method of choice.

Fifty-eight male albino rats from the National Institutes of Health were used both in the fracture study and in testing the performance of the static-loading assembly. When the body weight of an animal reached 350 grams the left humerus was fractured under ether anaesthesia. Five weeks after fracture roentgenograms were made and the fractures were arbitrarily graded on the basis of the degree of overriding and the angulation of the fragments. Rats with fractures of the same grade were apportioned uniformly among four groups. From the sixth through the twelfth week after fracture strontium or fluoride was supplied in the drinking water. One group was given 0.002N strontium nitrate (87.6 parts per million strontium) while a second group received 0.002N sodium fluoride (38.0 parts per million fluoride). A third group was given the strontium solution one day and the fluoride solution the next day. Controls received distilled water. Drinking water was available *ad libitum*, and the intake of each rat was measured. Animals were sacrificed twelve weeks after fracture, at which time roentgenograms were again made. After that, the breaking strengths and fluoride contents of the bones were determined.

The rat diet consisted of Purina Laboratory Chow, the fluoride content of which, in the case of those animals which did not receive the fluoride solution, was not sufficient to produce the typical striations on the lower incisors which begin to appear at fluoride intakes of nine to fifteen parts per million [10]. The relative magnitude of total skeletal uptake of fluoride by the rats which received the fluoridated water may be judged by a comparison of the fluoride contents of the tibiae of the rats on each regimen. On an ash basis the final fluoride content of the tibiae of the control rats and those receiving strontium was in each case of the order of 0.05 per cent, while that of the fluoride and strontium-fluoride groups was approximately 0.09 per cent and 0.08 per cent respectively.

The tibiae of these rats furnished data for appraising the strength-testing assembly as

TABLE III

AVERAGE RELATIVE BREAKING STRENGTHS OF REPAIRED ADULT RAT HUMERI

Regimen	No. of Rats	Average Total Intake of Mineral Supplement * (*Milligrams*) Sr	F⁻	Average Breaking Strength of Repaired Humerus (*Pounds*)
Fluoride	14		78.5	17.2 ± 4.0 **
Strontium and fluoride	14	83.1	39.2	15.0 ± 4.4
Strontium	15	164.3		18.3 ± 3.4
Control	13			17.6 ± 5.7
Total	56			17.0 ± 4.6

* The average daily intake of strontium was approximately 3.5 milligrams, that of fluoride was about 1.5 milligrams.

** Mean ± standard deviation.

a device for the measurement of resistance to fracture (Fig. 3). Table II indicates that of a total of fifty-eight rats the breaking strength of the right or left tibia varied on the average by 0.6 pound, or ± 3 per cent, from the mean breaking strength of the pair. This variation is not attributable entirely to the error of measurement, since it also includes the actual variation in breaking strength between the two tibiae.

Results in Table II fail to demonstrate any significant differences among the tibial breaking strengths of the various groups, with the possible exception of a slight depression in the strontium groups. This apparent effect may be fortuitous, since it is not evident elsewhere (Tables III and IV) in this series of experiments. The absence of a

TABLE IV

BONE LENGTHS AND BREAKING STRENGTHS IN ADULT RATS AFTER PROLONGED EXPOSURE TO STRONTIUM AND FLUORIDE

Regimen	Period on Low F⁻ Diet (*Days*)	No. of Rats	Avg. Body Weight (*Grams*)	Average Breaking Strength * (*Pounds*) Humerus	Tibia	Average Length * (*Millimeters*) Humerus	Tibia	Femur
Pre-Experimental	7	11	343	**	19.2 ± 1.93	28.7 ± 0.3	41.0 ± 0.61	37.3 ± 0.47
Following 180 days of experiment:								
Control	187	11	417	15.1 ± 2.55	22.5 ± 2.82	30.6 ± 0.56	42.3 ± 1.22	39.1 ± 1.06
0.002N NaF	187	11	403	16.4 ± 1.38	21.9 ± 2.68	30.7 ± 0.62	42.5 ± 1.11	39.4 ± 0.83
0.002N SrF_2	187	11	399	15.6 ± 1.81	21.6 ± 1.85	30.6 ± 0.67	42.6 ± 0.79	39.4 ± 0.82
0.002N Sr $(NO_3)_2$	187	11	381	16.1 ± 1.98	21.6 ± 3.29	30.5 ± 0.64	42.7 ± 0.93	39.1 ± 0.77
0.004N Sr $(NO_3)_2$	187	11	399	16.0 ± 1.61	22.4 ± 2.32	30.9 ± 0.49	42.9 ± 0.87	39.5 ± 0.68
All five experimental groups	187	55	400	15.8 ± 1.89	22.0 ± 2.57	30.6 ± 0.63	42.6 ± 0.96	39.3 ± 0.82

* Values for the left and right bones of each animal were averaged. Variation among animals is expressed in terms of the standard deviation.

** Measurement of the breaking strengths of the pre-experimental humeri was based on an anatomic landmark. Thus the results are not comparable with those of the experimental groups.

fluoride effect lends support to the finding that the incidence of fracture in young men is unrelated to fluoride exposure [11].

There was no clear evidence upon statistical evaluation that grade of fracture made important differences in the breaking strengths of the repaired humeri. Consequently the results for all grades of fracture were combined for the statistical analysis of the data on the repaired humeri (Table III). These data fail to show convincing evidence of the merit of any particular regimen in influencing the breaking strength of the repaired humeri. Considering the humeral-fracture experiment as a 2×2 factorial, a statistical analysis shows no significant fluoride effect, no significant strontium effect, and no significant fluoride-strontium interaction.

Angulation of the humeral fragments appeared to have remained fixed during the terminal seven-week period, as determined by superimposing roentgenograms of the same bone at five and twelve weeks following fracture. At twelve weeks after fracture the unreduced fractured humerus proved to be almost invariably several millimeters shorter than the sound one. Further comparison of the two sets of roentgenograms showed evidence of remodeling, or bony resorption and apposition, in varying degree about the convexity and the concavity, depending on the displacement of the fragments, that is, the degree of overriding, angulation, and protrusion. While those fractures which appeared most unfavorable, roentgenographically, usually possessed strengths below the group average, malalignment of some degree was not necessarily conducive to malunion or decreased strength. Perhaps an intimate, non-anatomic apposition of the fragments serves occasionally as a mutual onlay graft. With the exception of extreme cases, one may appreciate the difficulty confronting the clinician in assessing correctly by roentgenographic means the relative degree to which strength has been restored in a fractured member.

On the basis of the gross appearance of the fractured humerus, it was observed in a limited number of cases that the breaking strengths tended to be notably higher when the distal portion of the bony callus had increased considerably in bulk. Besides the influence of mere bulk, the histological findings in these few cases indicated an advanced stage of repair. For the most part, however, the gross appearance of the excised bone gave no clue to its relative strength. Theoretically a localized peripheral irregularity of bone producing a point of mechanical weakness can contribute directly to an unusually low breaking strength irrespective of an otherwise favorable gross external, roentgenographic, or histological appearance of the callus.

There was no adverse effect of either strontium or fluoride on the rate of growth, judging by the uniform gain in body weight of about thirty grams which was observed in all four groups over the final seven-week period. The total gain in weight for the entire twelve weeks was about fifty grams in all groups. Using gain in weight during the final seven weeks as a relative index of the state of general health, there was no indication of influence of the state of health upon bone healing. Correspondence between body weight gain and breaking strength, both values being either above or below the respective group averages, occurred in twenty-eight of fifty-six cases. A scatter diagram showed no relation between the two factors.

There seemed to be no obvious correspondence in this study between breaking strength and regimen, roentgenographic findings, or gain in body weight. The difficulty of favorably influencing fracture repair with strontium and fluoride may be readily appreciated when one realizes that supplements of dietary essentials known to be directly involved in bone growth, such as calcium and vitamin D, fail to hasten bone healing in otherwise normal patients on an adequate diet [3].

B. Histological Study of the Repaired Humerus

Following measurement of breaking strength the formalin-fixed humeral fragments

were decalcified with 30 per cent formic acid and ion exchange resin [2] after which they were embedded in paraffin, sectioned, and stained with hematoxylin and eosin. The object of microscopic examination was to determine whether there existed any correlation between the histological findings in the rats on the several regimens and the roentgenographic findings and measurement of breaking strength.

After fracture the fibrin in the hematoma is replaced by fibrous tissue and cartilage, and eventually by spongy bone which ultimately bridges the gap between the fracture ends. While the study of newly formed bone was relevant to the present work, decal-

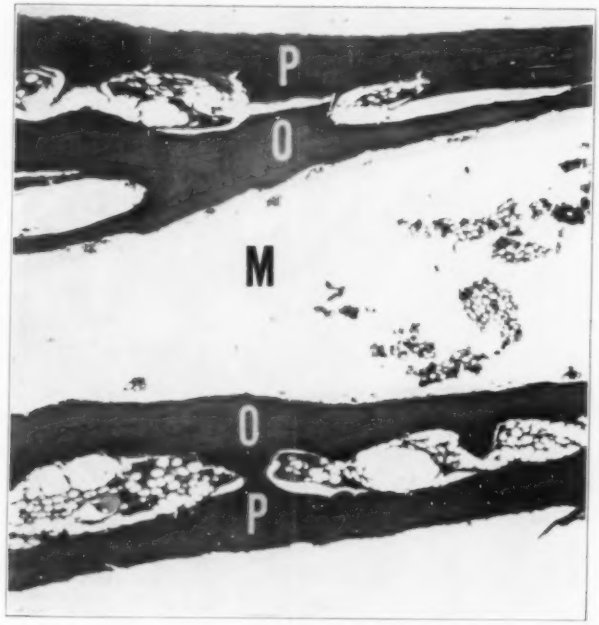

FIG. 4

Longitudinal section (× 33), decalcified and stained with hematoxylin and eosin, from the proximal fragment of a rat humerus twelve weeks after fracture. Note the bony collar surrounding remnant of the original cortex. Marrow elements are interposed between the cortex and the bony collar. *M*, central marrow cavity; *O*, remnants of original diaphyseal bone; *P*, outer bony jacket of periosteal origin.

cification of the specimens was not inconsistent with this objective, in view of the demonstration in fractured rat tibiae that new bone matrix—osteoid or uncalcified osseous tissue—is calcified as it is laid down [15].

The histological picture of the fractures at twelve weeks presented features sufficiently varied to preclude description of a "typical" lesion. In no instance had remodeling of bone approximated completion. The fibrous elements and cartilage which characterized the earlier phases of repair persisted in larger proportion in the small minority of rats in which slight mobility had been retained. With few exceptions the humeri displayed peripherally a continuity of bone between the fragments through an osseous band chiefly of periosteal origin. This band was usually separated from the old compact bone by marrow elements (Fig. 4). Frequently encountered was the centrally located spongy bone through which interconnection of the marrow cavities had been restored by means of multiple medullary channels among the trabeculae (Fig. 5).

No valid generalization can be made regarding a correlation between the micro-

scopic picture and breaking strength. One explanation for this may be the fact that a point of mechanical weakness which is not apparent histologically may materially influence the breaking strength of even a sturdy-looking bone when it is subjected to lateral stress. A somewhat analogous situation is that of dividing a length of glass tubing by merely scratching the glass and bending the tube at that point. It was noted, however, that extremely low breaking strengths were usually associated with the persistence histologically of some degree of fibrous tissue, cartilage, immature reparative bone, or interfragmentary gap. The stage of repair found microscopically at twelve weeks could

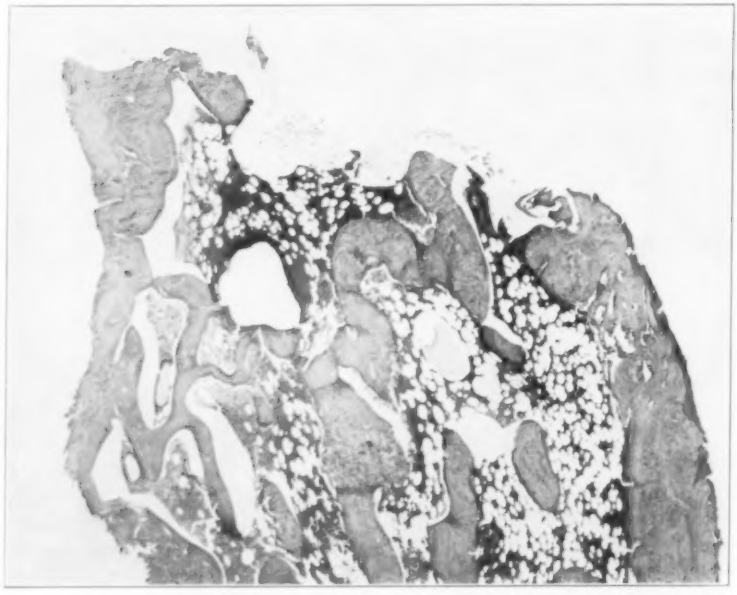

FIG. 5

Longitudinal section (× 33), decalcified and stained with hematoxylin and eosin, from distal fragment of an adult rat humerus twelve weeks after fracture showing vermiculated reparative bone formation in callus. The medullary interconnection with the proximal fragment has been restored. The new fracture line along the upper edge resulted from the breaking-strength test.

not be predicted from the roentgenographic appearance at five weeks, nor were there histological characteristics or other uniform signs which distinguished fracture lesions of rats on a particular regimen.

C. Effect of Prolonged Strontium and Fluoride Exposure upon Fracture Resistance

The tibiae of the adult rats in the preceding study (Table II) indicated absence of any clear influence of strontium and fluoride upon fracture resistance or breaking strength. The following experiment was undertaken because it was believed that a longer test period might reveal effects undetected in a seven-week study.

Sixty-six adult male white rats of the National Institutes of Health colony were placed on a low-fluoride diet (one part per million) [16] and distilled water when they attained a body weight of 345 grams. After one week on the diet, rats were assigned in rotation to one of the following groups: (1) pre-experimental—sacrificed after seven days on the low-fluoride diet, (2) 0.002N sodium fluoride, (3) 0.002N strontium fluoride, (4) 0.002N strontium nitrate, (5) 0.004N strontium nitrate, or (6) control—distilled water. The diet, distilled water, and the various strontium and fluoride drinking waters

were supplied *ad libitum*. Because of its low solubility, strontium fluoride cannot be prepared as a 0.002N solution. Consequently a stable, supersaturated (0.002N) solution was prepared by dissolving strontium nitrate and sodium fluoride in the proper concentration. Substituting a low-fluoride diet for the stock rat diet used in the fracture study would tend to amplify any possible differences resulting from an elevated fluoride intake. In addition, it was felt that administering a strontium fluoride solution would be more directly conducive to producing any possible synergistic effect of the two ions than alternating strontium and fluoride solutions on successive days.

Except in the case of the eleven rats in the pre-experimental group, the test period was 180 days, at the end of which time the rats were sacrificed and the freshly excised humeri, tibiae, and femora were placed in a 10 per cent neutral formalin solution. The lengths of the excised bones were measured, the length of the femur being determined from the condyles to the greater trochanter. In measuring fracture resistance the mid-point of the tested segment was also the mid-point of the humerus, or in the case of the tibia, a point seven millimeters above the fibular notch. Femoral fracture resistance was not measured.

There was apparently no effect from the various minerals on the longitudinal growth of the humerus, tibia, and femur (Table IV). Fracture resistance of the tibiae and humeri after 180 days on the various regimens appeared to be uninfluenced by a constant intake of strontium, fluoride, or the combination. As in the preceding study (Table II), Table IV indicates that fluoride consumption does not directly affect fracture resistance, these results again being consistent with the finding that fluoride exposure is unrelated to the incidence of fracture in human subjects [11].

SUMMARY

1. In a fracture study of twelve selected adult rats, autoradiograms (with use of Sr^{89}) showed that ossification seems to progress centripetally toward the interfragmentary space, and is generally more pronounced about the concavity of an unreduced fracture. The most extensive deposition of strontium in the callus appeared at about four weeks after fracture. A noticeable drop in strontium uptake by the fractured humerus appeared at about ten weeks.

2. In a limited chemical study of strontium deposition with a select group of twelve adult rats, findings were as follows:

a. An elevated fluoride intake did not favor increased accumulation of strontium either in the fractured humeri or in the sound humeri and femora.

b. The percentage of strontium taken up by the fractured unreduced adult rat humerus was twice that deposited in the sound limb, the increase being attributable chiefly to uptake by the callus. This ratio dropped appreciably toward the end of the repair period.

c. Judging by the comparative uptakes of the femora and sound humeri, the relative distribution of strontium among the femora and humeri of an individual animal (calculated as percentage of strontium) appeared to be related to the mineral content of these unfractured bones.

3. The reliability of measurements of relative breaking strengths of rat bones on a specially devised static-loading assembly has been demonstrated, and results were found to be satisfactory when an average absolute deviation of 6 per cent was tolerable.

4. From the sixth through the twelfth week after unreduced fracture of the left humerus, adult rats on a stock diet received as drinking fluids solutions of strontium, fluoride, a combination of these or distilled water.

a. Under the conditions of this experiment strontium, fluoride, or a combination of the two showed no significant effect upon the breaking strength of the fractured member.

b. There seemed to be no clear relation between the breaking strength of the

repaired humerus and its roentgenographic appearance, histological findings, or the mineral regimen.

5. A constant intake of strontium, fluoride, or strontium fluoride over 180 days did not show any significant influence of these minerals (in the concentrations used) upon fracture resistance of the humerus and tibia or upon longitudinal growth of the long bones of adult rats.

NOTE: The author is indebted to Dr. I. Zipkin for the fluoride analyses and to Mr. M. Schneiderman for statistical advice and suggestions.

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A Method of Bone Maceration

Results in Animal Experiments

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In 1895 Landerer succeeded in replacing the diaphysis of a finger with macerated bone from a dog. Lexer had reported the use of macerated grafts to fill defects in bone. In 1934 Orell [29] published a comprehensive study of the question whether preserved necrotic bone substance may be used in surgery. He freed ox bone of periosteum, endosteum, and of all of the other elements of the connective-tissue series by maceration, terming the resulting product "os purum". When this material is implanted between the compact bone and the periosteum of the tibia it is converted to "os novum" as a result of osteogenetic activity. During the next five years Orell's work was followed by a series of articles [1, 6–9, 21, 25–27, 30, 32, 34, 39–41] all of which, with one exception [41], reported successful results. Little or no further work on os purum was published thereafter. However, Goff [10], in 1944, reported successful application of the method clinically and recently informed us [11] that he continues to use this type of graft with good results.

In 1953 one of the authors (R. M.) reported that for three years he had used macerated grafts with excellent results in selected cases. In 1954 Lentz published a review of the patients treated in this Hospital.

It is difficult to understand why the macerated-graft method, with only a few exceptions, has been neglected. Was it because increasing experience did not bear out earlier expectations, or has the method fallen a victim to the bone bank?

We are inclined to the first of these two suggestions. All other published reports of animal experiments state that macerated grafts cannot be used successfully in surgery. Georg Axhausen believed that this graft ranked below all others in its suitability as a graft. Lentz, after careful examination, agreed with this estimate.

Recently, Maatz, Lentz, and Graf, in this Journal, reported the results of the spongiosa test, presenting contradictory findings concerning macerated bone. Some macerated grafts were incorporated earlier than homogenous grafts from the bone bank, while others produced a foreign-body reaction of the type usually found only in heterogenous or even boiled grafts. The authors suggested that this difference was due to a protein-bound biological intolerance which remained even after the process of maceration.

However, we are inclined to believe that the process of maceration itself plays a very important role in incorporation of the graft and that the few grafts replaced especially well by the host must be regarded, in some way, as chance events in the process of maceration. Accordingly, we decided to develop a method of maceration which would result in a transplant suitable for incorporation by the host.

Maceration means that the bone has been freed of all soft tissue. The literature on this subject is scanty [15, 28, 38] perhaps because this problem, in most cases, has been left to the skill of a few experienced in the field. The concept of maceration is not yet clearly understood among surgeons, and the methods used [4, 6, 13, 19, 24, 28, 38] for maceration, or what was believed to be maceration, have in some cases not been suitable. In those articles by Orell which were available to us we were not able to find a description of his method of obtaining os purum. In his important essay [29] he declared the preparation of bone to be a complicated and wearisome chemicophysical process to be executed

TABLE I

Graft						Host (Dogs)	
No. of Experiments	Species of Donor and Age (*Years*)	Agent and Time of Deproteinization	Degree of Deproteinization	Loss of Mechanical Value (*Per cent*)	No. of Days Implanted	Age (*Years*)	Callus in Hole Test
4	Dog 2–3	Solution of peptone (0.9 per cent)[5] 2 months (solution changed every two weeks)	Nearly complete	10	15	2–4	7/10
2	Dog 1–2	Running warm water 3 months[12]	Incomplete	0	15	2	6/10
4	Dog 2–3	3 per cent solution of antiformin at 100° C. 3 hours[21, 36, 37, 38]	Complete	50	15	2	6/10
5	Dog 2	5 per cent solution of antiformin at 100° C. 3 hours[21, 36]	Complete	60	15	2	7/10
10	Dog 2–6	3 per cent solution of sodium carbonate at 100° C. Up to 2 hours[38]	Complete	35	15	1½	7/10
4	Dog 2	Aqua destillata 100° C. 4 hours[28]	Incomplete		15	3	6/10
5	Dog 3	Potassium hydroxide 3 per cent 100° C. Up to 1 hour[21, 28]	Complete	70	15	2	6/10
8	Dog 2	Soapsuds 5 per cent 100° C.[5] Up to 4 hours	Complete	15	15	2	7/10
5	Dog 3	Solution of antiformin 3 per cent 37° C. 50 hours[5]	Incomplete	20	15	2–3	7/10
4	Dog 2–3	5 per cent solution of antiformin at 37° C. 40 hours[5]	Incomplete	20	15	2	6/10
6	Dog 2	3 per cent potassium hydroxide at 37°C. Three days[5]	Complete	30	15	1	6/10

only by specially qualified chemists. He gave the name of one firm which manufactured os purum.

We have supplemented the methods described in published reports by oral and written information from experienced workers in order to obtain a suitable foundation for our inquiries. It would by far exceed the scope of this report to give a survey of the methods used and their many minor differences. There are three ways of freeing bone of protein: the tedious bacterial proteolytic process, the short method of oxidation or reduction, and finally enzymal digestion. Fat is dissolved by standard solvents.

The method of maceration suitable for surgery must meet the following requirements: the deproteinization must be as complete as possible in order to reduce the

TABLE I

Callus in Autogeneous Fresh Graft	Biological Value of the Graft						
	Positive				Negative		
	Callus Formation	Creeping Substitution	Contact Between Host-Callus and Implanted Bone	Connective-Tissue Production of the Host	Inhibition of Bone-Production of the Host	Foreign-Body Reaction	Result
9/10	Ø*	Ø	Ø	+	+	+	Bad
8/10	Ø	Ø	Ø	+	+	+	Bad
8/10	Ø	Ø	+	+	+	+	Bad
9/10	Ø	Ø	Ø	+	+	+	Bad
9/10	5/10	+	+	+	+	+	Poor
8/10	1/10	Ø	Ø	+	+	+	Bad
8/10	3/10	0	0	+	+	+	Bad
8/10	2/10	0	+	+	+	+	Bad
9/10	2/10	0	0	+	+	+	Bad
9/10	0	0	0	+	+	+	Bad
8/10	2/10	0	0	+	+	+	Bad

* Ø: No callus formation.

protein-bound incompatibility between host and graft, without, however, reducing the biological value of the graft which may be due to the presence of a biocatalyst [17]. Biological values must not be diminished by the macerating agents. The mechanical qualities of the graft must not be affected by maceration to any appreciable extent; and finally, the macerated graft must be sterile.

In testing the material biologically the authors have used the spongiosa test (Maatz). In an earlier paper [23] published in this Journal, the method and the technique of evaluation were described. The uniformity of experimental conditions in this test is assured by use of a tube-shaped punch with which holes five millimeters in diameter are cut in the

TABLE II

Graft						Host (Dogs)	
No. of Experiments	Species and Age of Donor	Agent and Time of Deproteinization	Degree of Deproteinization	Loss of Mechanical Value (*Per cent*)	No. of Days Implanted	Age (*Years*)	Callus in Hole Test
20	Dog (homogenous) 2–3 yrs.	20 per cent hydrogen peroxide at 37° C.[5]	Complete	5	15	2	6/10
2	Dog (autogenous) 2 yrs.	20 per cent hydrogen peroxide at 37° C.[5]	Complete	5	15	2	7/10
10	Man 50 yrs.	20 per cent hydrogen peroxide at 37° C.[5]	Complete	5	15	2	7/10
30	Pig 5 days	20 per cent hydrogen peroxide at 37° C.[5]	Complete	5	15	2–3	7/10
40	Calf 6 weeks	20 per cent hydrogen peroxide at 37° C.[5]	Complete	5	15	1–6	7/10
20	Dog 1 year	Trypsin in Ringer's solution, alkalized pH 8.5 by $NaHCO_3$ at 37° C.[5] 3 days	Complete	5	15	1–3	7/10
30	Calf 6 weeks	Trypsin in Ringer's solution, alkalized pH 8.5 by $NaHCO_3$ at 37° C.[5] 3 days	Complete	5	15	1–3	7/10

spongiosa. Thus periosteal reaction is eliminated. The regenerative powers of spongiosa remain equally strong under almost all conditions, so that uniformity of experimental conditions is relatively easy to obtain. The bone cylinders may be easily reinserted or interchanged, either as living or as preserved or macerated bone. The possibility of performing several tests upon one animal at the same time offers a favorable base for comparing results. The authors performed two tests at a time on the distal ends of both femora and the proximal ends of both humeri of a dog; all eight tests were performed simultaneously.

The most important factors in determining the biological value of the implants are: (1) new-bone formation about invading blood vessels, (2) creeping substitution, and (3) envelopment by connective tissue (foreign-body reaction). The response of the host is determined by the hole test. The new-bone tissue grows concentrically.

After fifteen days nearly two thirds of the hole is filled by callus. This was found to be the most suitable time for comparative evaluation of the different implants [23]. As our intention in this study was primarily to examine the different methods of maceration in order to have a better basis for comparison, we implanted in each dog a fresh autogenous

TABLE II

Callus in Autogenous Fresh Graft	Biological Value of the Graft: Callus Formation	Positive: Creeping Substitution	Positive: Contact Between Host-Callus and Implanted Bone	Connective-Tissue Production of the Host	Negative: Inhibition of Bone-Production of the Host	Foreign-Body Reaction	Result
8/10	8/10	+	+	0	0	0	Good
9/10	8/10	+	+	0	0	0	Good
9/10	8/10	+	+	0	0	0	Good
8/10	10/10	+	+	0	0	0	Excellent
8/10	9/10	+	+	0	0	0	Excellent or good
9/10	7/10	+	+	0	0	0	Good
10/10	9/10	+	+	0	0	0	Excellent or good

and a fresh homogenous graft. This afforded an additional opportunity to exclude individual differences in reaction of the dog. In the spongiosa test, the age of the animal is of little importance. We used dogs from two to six years old. For technical reasons, the age had to be determined by the set of teeth. Growing animals are not suitable because the growing zones cause derangements.

If necessary, the test is supplemented by implants in muscle. These muscle tests were also performed in dogs. The hosts were dogs from two to six years old. Spongiosa plugs, obtained by the method described, were also implanted. Their length amounted to nearly fifteen millimeters. The grafts were implanted in the muscles of the back. The duration of this test was also fifteen days to correspond to the time required for the spongiosa test. Fresh autografts regularly show marked formation of callus. This result was confirmed by thirty controls. As we were interested only in gross differences in the mechanical value of the graft, the simplest tests for breaking point were used.

Spongiosa grafts were loaded to the breaking point by a lever-arm of fifteen millimeters vertically to the longer axis. The standard mechanical value of the fresh non-treated bone was determined on the basis of the average value of four grafts taken from

Figs. 1-A to 1-D: Results of spongiosa tests fifteen days after implantation. The tests were all made in the same dog.

Fig. 1-A: Hole test showing the productivity of the host. About two-thirds of the defect has been filled by host callus.

Fig. 1-B: A homogenous graft macerated in a 5 per cent soapsuds solution has produced a marked foreign-body reaction. The host callus is inhibited. The trabeculae have been enveloped in fibrous tissue and there has been extensive lacunar resorption. No contact has been established between the host callus and the macerated bone of the graft.

Fig. 1-C: A homogenous graft preserved in the deep freeze (−30 degrees centigrade) shows a slight inhibition of bone production in the host. At the periphery the host callus has made contact with the implanted graft, and the beginning of creeping substitution may be seen in this area. On the whole, however, there is a distinct decline in bone production as the center of the hole is approached. Reparative activity is greatest at the periphery and least at the center.

Fig. 1-D: An entire graft macerated in a 20 per cent hydrogen peroxide solution has been replaced by newly formed host callus, and this is almost as marked in the center as at the periphery. There is no evidence of a foreign-body reaction. The implant has incited callus formation. This was a heterogenous graft taken from a young pig.

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the same skeletal region; this average value was arbitrarily set at 100. The diminution of value of the grafts through maceration was then calculated in percentages.

Table I lists those experiments in which either the maceration was not complete or was complete but the mechanical value had been so diminished that the process had no practical value.

Table II lists the biological value of those grafts which had been completely macerated without suffering a complete destruction of their mechanical value. The results were compared with the tests on fresh autogenous and homogenous grafts implanted in the same animals simultaneously. Finally the results were compared with those from the hole test. These are average values of grafts treated by the same methods.

It was shown that all the methods of maceration used hitherto are insufficient. An example of this is a homogenous graft macerated in a 5 per cent solution of soapsuds. Fifteen days after implantation proliferation in the host was markedly inhibited; there was marked connective-tissue degeneration (Fig. 1-B). The scant callus formation of the host did not reach the transplanted graft at any point. The trabeculae of the latter were enveloped by connective tissue rich in fibers. Gradual invasion of the graft by osteoclasts was taking place; these were scant in the center but quite numerous in the periphery. There was no evidence of new-bone formation (Fig. 2). Thus we may confirm the fact that none of the methods of maceration hitherto known are suitable for surgical purposes. We may anticipate our later findings by stating that the cause for this lies in an inadequate removal of protein, in alteration of the protein, or in remnants of breakdown products which are not tolerated by the host.

Following the observation that with hydrogen peroxide in 2 to 5 per cent solution, as it is used for bleaching, it was possible to detach remnants of tissue from grafts which had been incompletely macerated, one of the authors (A. B.) attempted deproteinization in a more concentrated solution of hydrogen peroxide. The result was satisfactory, as the data in Table II reveal.

Thus in hydrogen peroxide was found a substance which in a short time, without notable injury to the mechanical properties of the graft, makes possible complete maceration of grafts and which does not reduce their biological value but on the contrary increases it. Furthermore, hydrogen peroxide has the advantage of leaving no remnants in the preparation; its breakdown products (water and hydrogen), together with the gelatinous substances, are washed out in running water, and are destroyed in the next step, the drying process. The hydrogen peroxide permits maceration within the realm of physiological temperatures, so that protein in the pure bone substance is altered but destruction of possible biocatalysts through the use of heat is avoided.

The biological tests in general have shown satisfactory results, sometimes exceeding our expectations. We soon learned that deproteinization by hydrogen peroxide may be carried so far that specific proteins play an entirely secondary role. The age of the donor,

FIG. 1-B

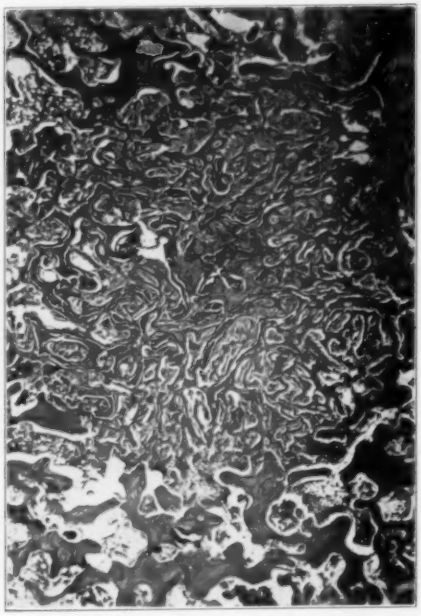

FIG. 1-D

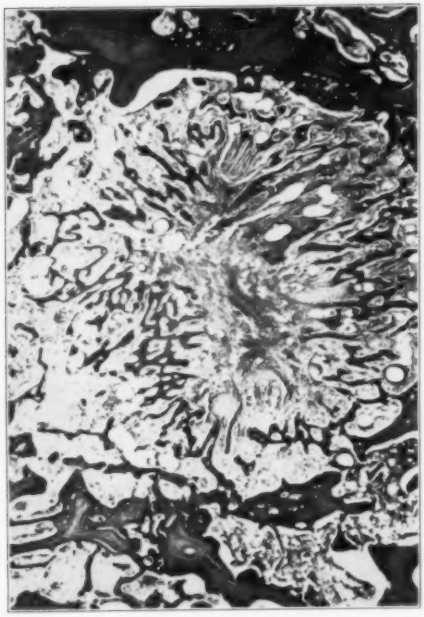

FIG. 1-A

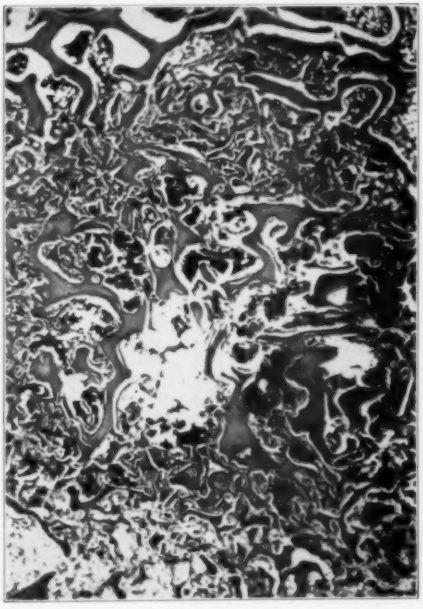

FIG. 1-C

Fig. 2: Photomicrograph (× 75) of a section from the periphery of the graft in Fig. 1-B macerated in a 5 per cent soapsuds solution shows, at the right, inhibited activity of the host callus and, at the left, implanted lacunae enveloped by fibrous granulation tissue. There is evidence of lacunar resorption. No contact has been established between the host callus and the implanted graft. A strong foreign-body reaction is evident.

Fig. 3: Section (× 75) from the center of the graft in Fig. 1-D macerated in a 20 per cent hydrogen peroxide solution. The last of the trabeculae of the implanted graft have disappeared in the process of incorporation. There is marked new-bone formation, partly by invading blood vessels, partly by creeping substitution.

Fig. 4-A: Section (× 12) of a spongiosa graft, taken from a pig a few days after birth. The graft was macerated in a 20 per cent hydrogen peroxide solution and implanted into the muscles of the back. The specimen shown was removed fifteen days after implantation. Marked metaplastic formation of new bone is evident.

Fig. 4-B: A section (× 75) from the right side of the implanted graft, showing marked bone regeneration. A remaining part of the graft may be seen in the lower left.

on the other hand, is of far greater importance. Bone from a very young animal is especially suitable. An example of this was seen in a spongiosa test, made at fifteen days, of a graft taken from a pig a few days after birth; this graft had been macerated in a solution of 20 per cent hydrogen peroxide. Marked new-bone formation had taken place throughout the entire graft, in the center as well as at the periphery. There was almost no evidence of a decline in bone production toward the center, and no evidence of biological intolerance of tissue. For the most part, the graft had been replaced by bone tissue from the host. The macerated graft implanted in the spongiosa was shown to provide the greatest stimulus to the regenerative power of the host, being superior even to the fresh autogenous graft. The trabeculae are replaced by living bone more rapidly, and the younger the donor the more rapid the resorption. From the hole test we learn that this graft has the property of inducing callus formation. Host callus from the hole test made after the same time interval shows callus formation extending nearly halfway to the center (Fig. 1-A). The effect of this graft exceeds by far the function of a scaffolding.

The graft instigates the production of bone; this is shown particularly well by the results of the muscle test. Of thirty heterogenous grafts (grafts from calves and pigs implanted in dogs) deproteinized by hydrogen peroxide, nineteen showed callus production in the granulation tissue of the muscles after fifteen days (Figs. 4-A and 4-B). At fifteen days metaplastic production of new bone was evident and, starting from it, beginning replacement of the implanted trabeculae. This result has not been achieved hitherto with macerated grafts. Even in homogenous grafts implanted under the most favorable conditions this result was obtained only after a much longer period of time. Lentz obtained the same result with homogenous spongiosa grafts at four weeks; W. Axhausen obtained the same result after implantation with cortex at six weeks. Figure 4-B shows the microscopic focus of marked new-bone formation within the pure muscle bed. The macerated bone induces metaplasia in the proliferating host tissue and bone is formed. Thus pure bone substance, after removal of all soft tissue, is seen to possess the property of stimulating bone production.

When we take into consideration that these muscle implants are cancellous-bone grafts, placed for twenty-four hours in 20 per cent solution of hydrogen peroxide, it seems hardly possible that this bone-producing stimulus is due to a biocatalyst as Levander assumed. In the process described all organic compounds which have the characteristics of biocatalysts must be destroyed. Moreover, these substances would be extracted during the removal of fats, a process which will be described later in this report. To test the accuracy of our results, some of the grafts which had been macerated in hydrogen peroxide were boiled for fifteen minutes and we found that they retained the ability to stimulate bone production. However, the firmness of the grafts macerated by hydrogen peroxide is almost completely destroyed. They are friable and therefore useless for surgical purposes.

These observations drew our attention to the peculiarity of maceration by hydrogen

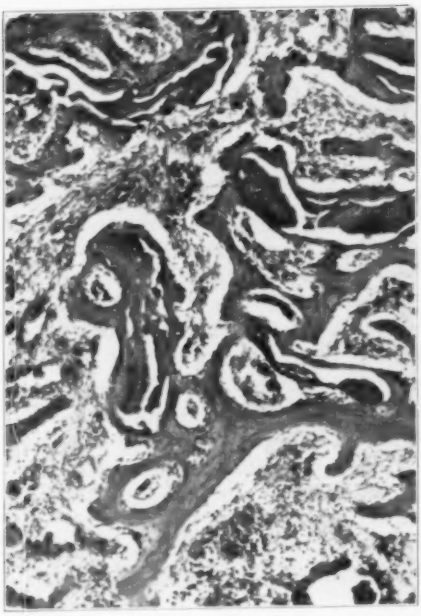

FIG. 3

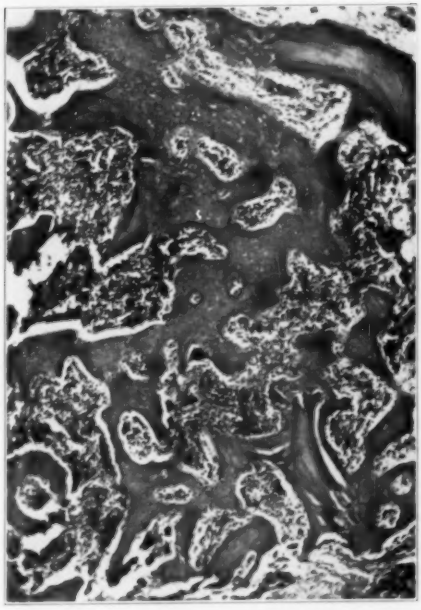

FIG. 4-B

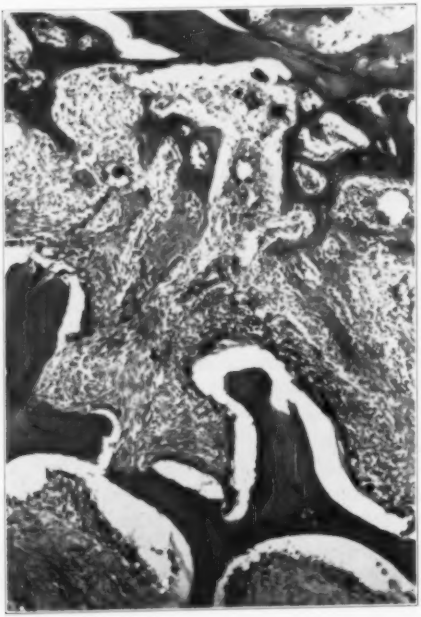

FIG. 2

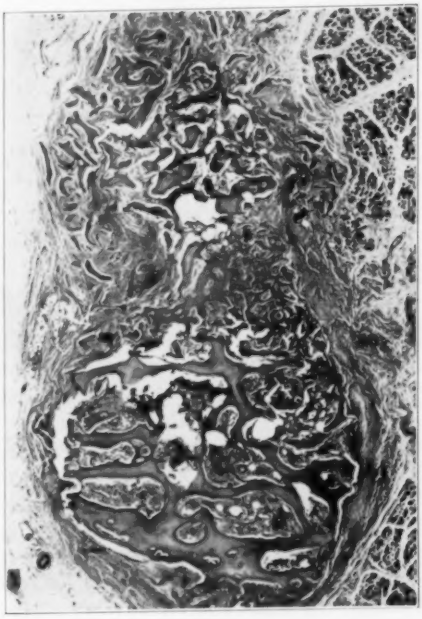

FIG. 4-A

peroxide. In 1952 Robinson studied cancellous and cortical bone by electron microscopy. For our purposes, it is sufficient to recall that pure bone substance is built of a reticulum of collagen fibers, in the interstices of which are deposited crystalline inorganic substances (Fig. 5). These are mineral salts of a complex chemical structure such that living cells may hold them in solution and secrete them for use in replacing dead bone with new bone in the manner of an enzymal reaction.

The mechanical compactness of bone is lost when calcium salts have been removed by means of acid; it is also lost when the organic substances have been removed. Thus the interweaving of organic and inorganic substances described above must be held responsible for the mechanical compactness of bone. Hydrogen peroxide macerates through oxidation of the organic substances. In contrast to antiformin, which also effects maceration by oxidation, hydrogen peroxide leaves the fibers of the reticulum undisturbed for a relatively long time. This has been demonstrated by the minimal loss of bone compactness after the bone has been treated with hydrogen peroxide. Obviously, however, the hydrogen peroxide penetrates very close to the sustaining fibers, so that the bone is made accessible from within and the younger the graft, the more easily it may be opened up. Grafts which have been thoroughly macerated in hydrogen peroxide show no trace of nuclei; this means that the medium enters the lacunae. Thus we may explain the ability of a completely macerated graft to stimulate callus formation and to induce metaplastic bone production on the basis both of a ready availability of building materials in a predetermined pattern, and of the presence of calcium salts. In a later publication one of the authors (A. B.) will discuss the experimental tests in order to support this explanation.

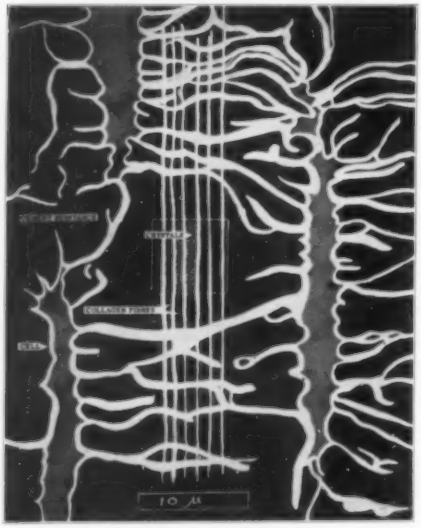

FIG. 5

Schematic representation of the details of construction of compact bone as magnified at about × 3,000. (Reproduced by permission from An Electron-Microscopic Study of the Crystalline Inorganic Component of Bone and Its Relationship to the Organic Matrix, by R. A. Robinson. *The Journal of Bone and Joint Surgery*, **34-A**: 399, Apr. 1952.)

For extraction of fat, pure ether was used to retain physiological temperatures. Immersion in a fat-dissolving medium is not sufficient, because the medium for solution is far too quickly saturated. Therefore we rely on apparatus such as Schwerin's for anatomical studies, or on Soxhlet's apparatus. The solvents used—carbon tetrachloride, benzine, or similar substances—require temperatures of 65, 80, or 120 degrees centigrade. The boiling point of ether is 34.6 degrees centigrade. From the boiling ether (Fig. 6) vapors arise and steam around the preparations lying on a grate above the surface of the liquid. The vapor enters the capillary channels and condenses, at the surface, into confluent drops. At the head of the vessel, the ether vapor coming into contact with the preparations circulates within a refrigeration apparatus, condenses, and drops down upon the preparations. The fatty substances are then released by the condensing gases and collect in the ether bath. Pure ether only evaporates, so that the circulation begins anew. Thus only the vapor from the ether and pure liquid ether will affect the bones. When all fat has been removed—a process which requires nearly twelve hours—the ether is forced to leave the chamber when the cooling apparatus is turned off.

The preparations dried in this way proved to be free of pathogenic organisms in each case and were therefore ready for transplantation. Sterilization through heat was unnecessary, so that we were successful in our endeavor not to exceed physiological temperatures during the process of maceration. Hitherto, macerated bone was sterilized in boiling water, in normal saline solution, or in antiseptic solutions. We wanted to avoid the last of these particularly, in order to exclude all remnants of foreign bodies. For the same reason we were careful to keep all parts of the apparatus made of glass or china, free from any metals which might cause chemical reactions.

The sterilizing effect of the extraction apparatus was actually to be expected. The cell walls of living organisms consist of a latticework of high-molecular protein, with lipoid membrane extending between them. Even the most powerful organic solvents are not strong enough at room temperature to guarantee sterilization. The extracting power of any medium is determined by its chemical activity which in turn, however, is dependent upon the molecular activity of its parts, which is proportional to the temperature prevailing. By the activity of ether vapors, the lipoid membranes are separated from the structure of the cell walls, and thus the micro-organism is destroyed. Moreover, no micro-organism can survive maceration for forty-eight hours in a 20 per cent hydrogen peroxide solution.

Since, during some phases in the preparation of the grafts, the specimens cannot be kept entirely free from pathogenic micro-organisms, sterilization at the conclusion of the process is necessary. Such sterilization is obtained simultaneously with the depletion of fat within the extraction apparatus.

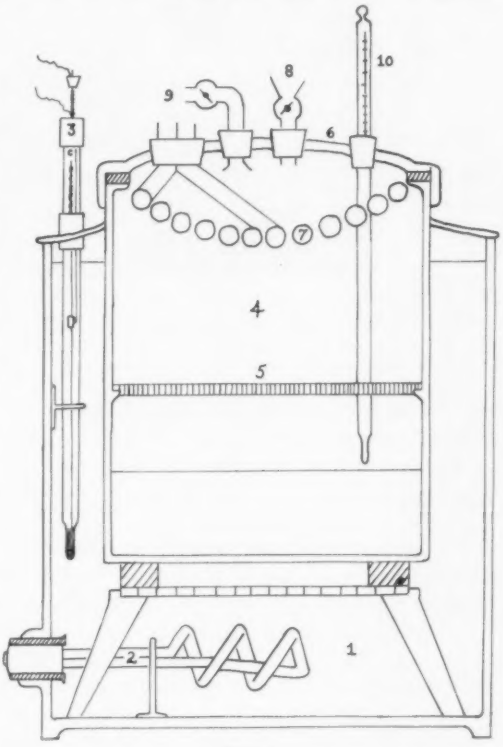

FIG. 6

Extraction apparatus used both for the extraction of fat and for the sterilization of macerated bone. *1*, water bath; *2*, heating apparatus; *3*, thermostat; *4*, extraction chamber; *5*, grate on which bone is placed; *6*, overchanging lid with rubber packing; *7*, refrigerating coils; *8*, opening by which ether is admitted; *9*, waste pipe for escaping ether vapors; and *10*, thermometer.

From animal experiments, it is clear that transplants to be used in surgical procedures should be prepared as follows:

The bone should be obtained from a six-week-old calf. Our experiments (forty implantations on ten dogs) showed that bones from animals no more than a few days old retain an especially high biological value after deproteinization by hydrogen peroxide. However, it was also shown that the mechanical quality of grafts taken from very young animals is inadequate. Bone from calves six weeks old showed a compactness sufficient for surgical purposes while the biological value after deproteinization ranged from excellent to good. Figure 7 shows an example. Sterilization of these bones is not necessary. The bone is sawed in suitable sizes before deproteinization.

The next step is that of *deproteinization* in 20 per cent hydrogen peroxide solution in

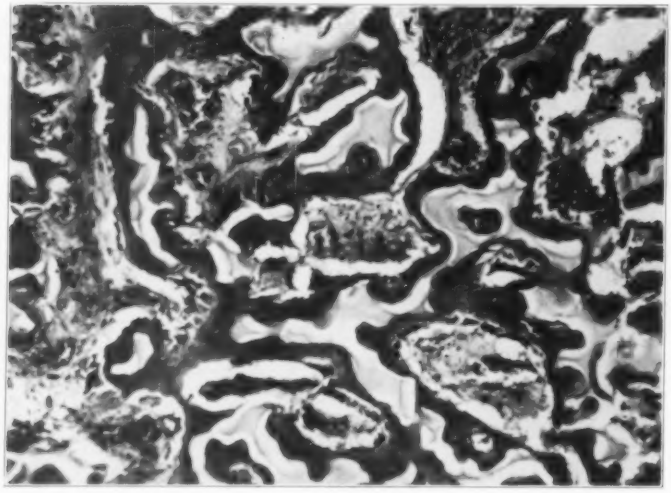

FIG. 7

Photomicrograph (× 75) of a section from the center of a graft obtained from a six-week-old calf. Deproteinization was done by the new method. The biological value of the graft was found to be excellent.

the incubator, at 37 degrees centigrade. The vessels should be of china or glass. A grate is placed over the surface of the solution to keep the bones immersed. The solution should be changed two or three times during the forty-eight-hour period and each time partly dissolved cartilaginous and tendinous remnants should be removed by mechanical methods.

The next step is the washing out of gelatinous substances under running water for about twenty-four hours. In this way, these components are removed from the spaces between the trabeculae and out of the Haversian systems.

The deproteinized bones are then dried in an open extraction chamber. The temperature of the chamber is controlled by a thermostat regulated by a water bath, so that the temperature does not exceed the desired level. In order to prevent the water from dripping to the bottom of the chamber the grate of the extraction chamber should be covered with blotting paper. The blotting paper is removed when the drying process is completed.

The removal of fat is the next step. During this process the temperature of the water bath is raised to 60 degrees centigrade. The level of the ether must remain several centimeters below the grate on which the bones are lying. The chamber must not contain metals of any kind. After the chamber has been closed the refrigeration apparatus under the ceiling of the chamber is turned on. After twenty-four hours, the ether is forced to leave the chamber when the refrigeration is turned off and is caught in a condenser; it may be used again after metallic sodium has been added.

The prepared bone is now sterile and is cut into various shapes and sizes suitable for operative use. The grafts are preserved in sterile containers. Each time the complete process of maceration has been concluded, a specimen from that group is examined bacteriologically, and the material is released for use only after this has been proved to be sterile. The grafts may be mailed out in glass ampules. It is believed that they can be preserved indefinitely without losing their biological value. In grafts preserved for one year we found no evidence of diminution of biological potency.

In fifty-eight tests performed on twenty-three dogs the results were biologically excellent or good in forty-nine. The results in the remaining nine were not quite as satis-

factory, because they did not reveal a foreign-body reaction and callus production was less marked. We are aware that favorable results in animal experiments do not necessarily apply to clinical practice. To the present time, however, we have used grafts deproteinized by the method described in nearly 200 patients with excellent results. These will be reported at a later date.

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The Water Content of Bone

I. The Mass of Water, Inorganic Crystals, Organic Matrix, and "CO_2 Space" Components in a Unit Volume of Dog Bone * †

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INTRODUCTION

Chemical analyses of bone are usually expressed in weight per cent. For instance so many grams of calcium are found in so many grams of fresh or dry whole bone or in some variety of bone ash. Some investigators, such as Tsai and Lin, Hulsen [28], Rauber [28], and Krause and Fischer [28], recorded their data in terms of weight per volume but this is not common practice [3, 4, 20]. Deakins [7, 8] showed the usefulness of the latter method when studying the water content of enamel.

As in enamel, when osteoid (the organic matrix of actual bone tissue in a piece of whole bone) is once formed by the bone cells (osteocytes), its volume does not change during calcification. This makes volume relationships significant in bone analyses.

Biophysical methods of studying bone sections, now coming into prominence, are autoradiography [1, 9], microradiography [2, 13], interference microscopy [6], and electron microscopy [23]. Combinations of these methods can be used [10, 11, 12]. These methods, as well as regular photomicrography of bone sections, yield two-dimensional pictures. However, even the thinnest sections of bone or of any other tissue have some thickness; and, for this reason, all of the techniques mentioned, as well as studies of bone sections in the light microscope, involve three dimensions—length, width, and thickness. This means that the impressions gained by all studies of tissue sections involve the concept of volume.

In the case of microradiographs depending on the characteristics of the x-ray beam, such as wave length, and of the section thickness, one may measure the relative quantity of an element. For instance, relative calcium mass may be measured in various parts of an undecalcified bone section [2, 13]. Once the level of complete calcification is established, then the relative calcification of any volumetric portion of the whole specimen can be calculated. A weight-per-volume concept is implicit in such studies, the x-ray absorption in any unit of the section being proportional to the mass of calcium in that unit volume.

Autoradiography shows the comparative amounts of an isotope in different volume portions of a tissue section. In this case there is a relation between the number of tagged atoms and the volume of the tissue in which they are lodged to the degree of photographic exposure. A mass is represented by each calcium atom emitting radiation. The section thickness, when known, allows one to calculate the tagged atoms per unit volume of the section. The number of radioactive to non-radioactive atoms may be calculated, given certain factors, with the aid of a microradiograph of the same tissue section. Thus a mass-per-unit-volume concept is involved in such combined autoradiographic-microradiographic techniques [11].

By interference microscopy the mass per unit volume of a tissue section can be measured. Thus Davies and Engstrom found that, regardless of the percentage of completeness of calcification of a unit volume of osteoid prior to decalcification, the mass per unit volume of the osteoid after decalcification was practically the same in all parts of a bone section studied by means of interference microscopy. Of course, since the weight of a unit volume of the mineral crystals of bone (or, in other words, the hydroxyapatite

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† Based on a paper read at the Annual Meeting of The American Orthopaedic Association, White Sulphur Springs, West Virginia, June 19, 1955.

crystals) is a little more than twice as great as the weight of an equal volume of osteoid, they found that the mass per unit volume of calcified osteoid increased with increasing calcification as determined by interference microscopy. In other words, the density of the dry calcified osteoid increased with increasing completeness of calcification since $\frac{\text{mass}}{\text{volume}} = \text{density}$.

Observations made on sections of bone with the electron microscope were in fact the stimulus for this present study. It became apparent when bone formation was studied by this method[24] that osteoid, which characteristically contains a large mass of collagen fibers per unit volume, did not disappear during calcification. If any change did occur, the fibers became slightly larger and occupied slightly more of a unit volume of osteoid as calcification proceeded during the maturation of a unit volume of osteoid.

It should be noted that Howard and Rubin[20] demonstrated metachromasia in decalcified bone sections. Metachromasia is generally associated with the presence of cement substance. This experiment suggested that cement substance was not lost during calcification of osteoid. Recent work would tend to confirm this earlier experiment[27]. This concept contradicted one that is sometimes gained from a gravimetric study of dry bone—namely, that the organic component decreases as the inorganic component increases. It became apparent that an analytical investigation of bone should be made in order to determine the weight-to-volume relationships of the various components of hydrated and dry bone. Our interest was particularly in the water component which seemed to be the one most likely to be displaced by bone crystals in a fixed volume of osteoid during calcification. Deakins previously suggested that the apatite crystals and carbon dioxide replaced an equal volume of water in the organic matrix of tooth enamel during its calcification[7, 8].

At this point a few definitions are in order:

1. "It is in consequence of a body's mass that it possesses inertia and that the earth is able to pull upon it with a gravitational force which we call weight. The more mass a body has the more weight it possesses. One is proportional to the other. Mass is measured by weighing."[26]

2. "The density of a body is the mass of a unit volume of the substance or the mass of a body divided by its volume: $D = \frac{M}{V}$."[26]

3. "The specific gravity is the ratio of the density of the body to that of water. In the metric system the density and specific gravity are expressed by the same number since the density of water is taken as 1.0."[26]

It is apparent that the newer biophysical methods force one to think of the components of bone in terms of mass (which is measured as weight) per unit volume. If data from classical gravimetric bone analysis are to be correlated with data obtained by autoradiography, microradiography, interference microscopy, and electron microscopy[24] or even photomicroscopy, they must be expressed in terms of weight per volume rather than as weight per cent of total weight, or be readily convertible to such terms.

Therefore, an investigation of bone samples from the tibial cortex of puppies and dogs was undertaken with the purpose of analyzing it chemically and expressing the gravimetric data in terms of the volume occupied by the mass weighed.

METHOD

1. Full-thickness specimens of the cortex of tibiae from dogs and puppies were used. The specimens were kept moist for about an hour until they were mechanically cleaned of superficial marrow and periosteum in the laboratory. The specimens were usually

about two by 0.3 by one centimeters in size, although smaller specimens were sometimes used. One small hole was drilled in the bone through which the suspension wire for submerged weighing procedures was inserted.

2. The specimens, stripped of available marrow and periosteum, were called whole-bone specimens. They, of course, contained bone cells, blood vessels, and marrow surrounding the vessels in the Haversian canals. Bones were weighed when they were first cleaned and were still moist, and they were weighed later after soaking in water at 4 degrees centigrade for various periods of time up to several weeks in an effort to find (1) if the bone specimens gained weight and (2) if the specimens lost weight during such soaking in distilled water at pH 6.9.

3. The bone specimens were then suspended on a fine wire and were weighed while submerged in a water bath. This was the weight of the hydrated bone specimen submerged in water.

4. Excess surface water was lightly blotted off and the specimens were weighed under cover in a chain-omatic Christian Becker balance. This was the weight of the hydrated bone specimen in air.

5. The specific gravity of the hydrated bone specimen can be obtained when one subtracts the weight of the specimen in air from its weight when submerged in water and then divides the weight of the specimen weighed in air by the remainder:

+ In Air	weight of dry bone specimen (880 milligrams)	plus	weight of water retained by specimen in air after hydration (120 milligrams)	equals	weight of hydrated bone specimen in air (1000 milligrams)
− In Water	dry weight of specimen (880 milligrams)	minus	weight of water displaced by the *dry* bone volume (380 milligrams)	equals	weight of hydrated bone specimen submerged in water (500 milligrams)

Subtracting submerged weight from hydrated weight of the bone specimen in air gives the following result: 500 milligrams.

This result actually represents:

weight of water retained by the specimen in air after hydration (120 milligrams)	plus	weight of water displaced by the *dry* bone volume (380 milligrams)	equals	volume of the dry bone plus volume of the water retained in air, expressed as milligrams of water (500 milligrams)

Since: $\frac{W}{V}$ = specific gravity, $\frac{1000}{500}$ = the specific gravity of this hydrated sample = 2.0.

From this one may determine the *density* of the hydrated bone specimen: one gram of water equals one cubic centimeter of water only at 4 degrees centigrade. At room temperature or 27 degrees centigrade, the weight of one cubic centimeter of water is 0.99654 gram instead of one gram. Therefore: $\frac{500 \text{ milligrams}}{0.99654}$ = 501 milligrams or: 0.5 gram of water at 27 degrees centigrade actually represents 0.501 cubic centimeter of water. It follows that substituting in the formula $\frac{W}{V}$ = density: $\frac{1000}{501}$ = *density*, the density of this hydrated sample of bone is 1.9961, whereas its hydrated *specific gravity* is 2.0.

Since the weighing error was ± one milligram in these studies and few samples exceeded a hydrated weight in air of one gram, the term *density* was used instead of *specific gravity* for brevity. Also biophysical methods usually determine density rather than specific gravity. Thus, this parallelism of terms is believed to be warranted here.

6. It was found that if a number of hydrated bone specimens had the same density, then they also contained, within the limits of error, similar amounts of mineral ash (ashed at 600 degrees centigrade) and organic matter decalcified in versene. This fact is illustrated in Graphs I-A to I-E (pages 171–173) and Graphs II-A to II-D (pages 178 and 179). Therefore, it was customary to obtain the density of the hydrated specimens and to use some at each density level for ashing and others at each level for the versene-decalcification procedure. The specimens chosen for ashing were then dried. The specimens from adult dogs chosen for decalcification in versene could be dried and then rehydrated and decalcified without significant alteration. However, puppy bone, having a density when hydrated of 1.7 or below, failed to regain up to 15 per cent of full weight on rehydration after any of the four drying procedures tested. Therefore, in the case of puppy bones it was standard procedure to obtain dry weights only on those specimens that were to be ashed at 600 degrees centigrade in order to avoid subsequent weighing errors on the specimens of hydrated decalcified organic residue.

Four methods of drying the bone were tried and compared: (a) drying to constant weight in an oven at 100 to 105 degrees centigrade in air; (b) drying in a high vacuum in a freeze-drying apparatus (0.01 millimeter of mercury) without prior freezing of the bone; (c) drying at room temperature (25 degrees centigrade) over silica gel at a reduced air pressure created by the laboratory suction line (225 millimeters of mercury); (d) drying to constant weight in an oven at 50 degrees centigrade in air. The first of these methods was used after the preliminary tests.

After drying to constant weight the specimens were weighed dry in air. After the dry and the submerged weights were obtained, the dry volume of the bone sample could be calculated. This method could also be used to obtain the dry volume of ashed bone and of dry organic matrix of bone decalcified in versene. From these determinations one can calculate the dry density of the sample. It will be noted that in the calculation of the hydrated density the weight of a submerged bone specimen can be analyzed as follows:

(a)		(b)		(c)
dry weight of specimen (880 milligrams)	minus	weight of water displaced by the *dry* bone volume (380 milligrams)	equals	weight of *hydrated* bone specimen submerged in water (500 milligrams)

It follows that if *c* is subtracted from *a*, the result is *b*. The reason for this is that any water in a specimen becomes weightless when that specimen is submerged in water:

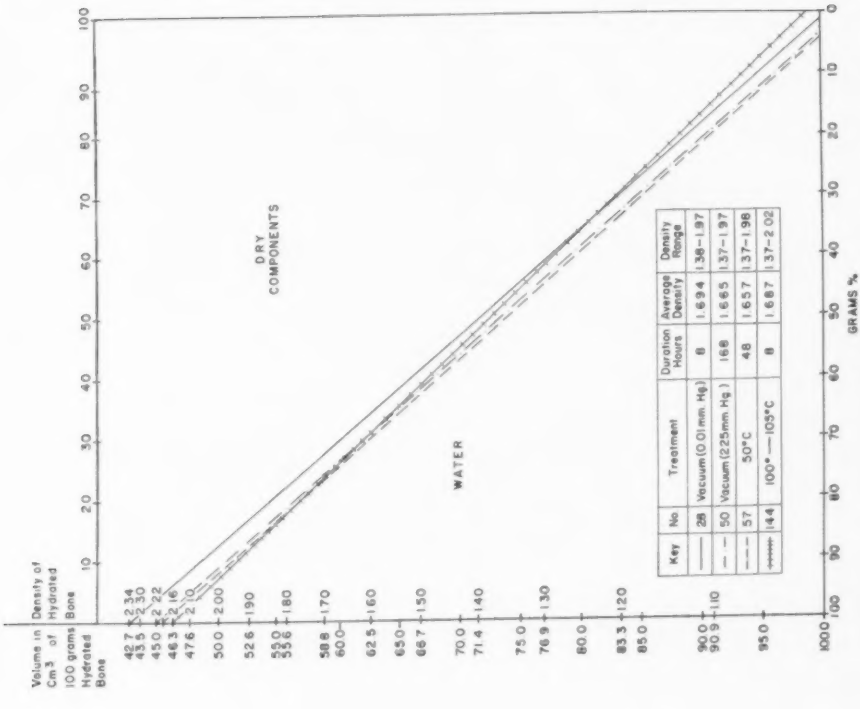
880 (a) − 500 (c) = 380 (b) or dry bone volume measured as displaced water. Since:

$\frac{W}{V}$ = specific gravity, it follows that: $\frac{a}{b}$ = the specific gravity of the dry bone specimen:

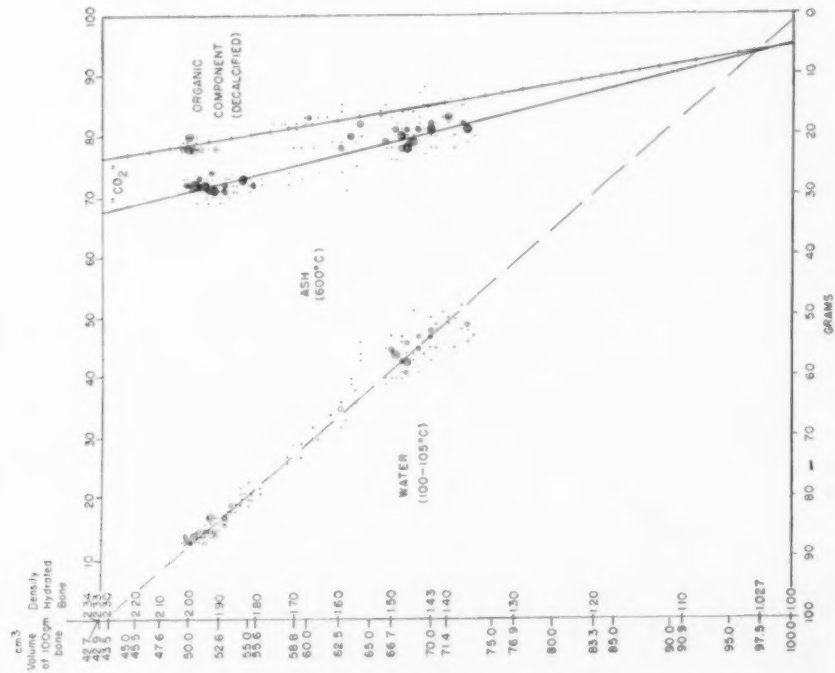
$\frac{880\ (a)}{380\ (b)} = 2.31$ = density of the dry bone specimen when corrected for temperature.

Theoretically, the determination of the density of a sample of dry bone is significant to the second decimal place only if the weight of the dry sample in air is 1000 milligrams or more when there is a ± one milligram weighing error and if the weight of the dry sample is 800 milligrams or more when there is a weighing error of ± 0.5 milligram in the laboratory procedure.

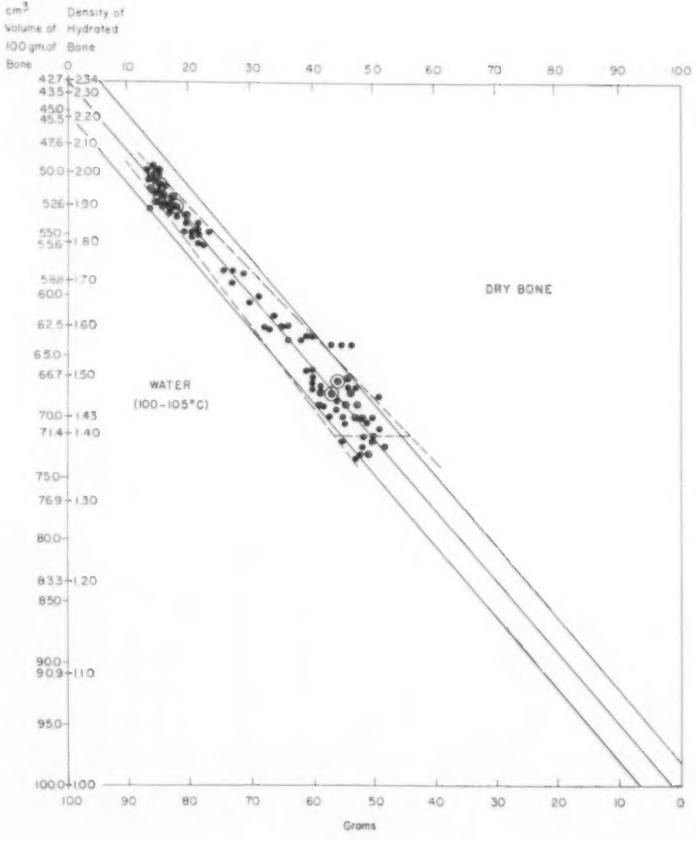
7. The ash content was obtained by heating bone samples in a silica dish or platinum crucible in a muffle furnace at 600 to 650 degrees centigrade for eight hours. By that time


Volume in Cm3 of 100 grams Hydrated Bone
Density of Hydrated Bone
DRY COMPONENTS
WATER
GRAMS %
Key | No. | Treatment | Duration Hours | Average Density | Density Range
—— | 28 | Vacuum (0.01 mm. Hg) | 8 | 1.694 | 1.36–1.97
– – | 50 | Vacuum (225 mm. Hg) | 168 | 1.665 | 1.37–1.97
– – – | 57 | 50°C | 48 | 1.657 | 1.37–1.98
····· | 144 | 100° — 105°C | 8 | 1.687 | 1.37–2.02

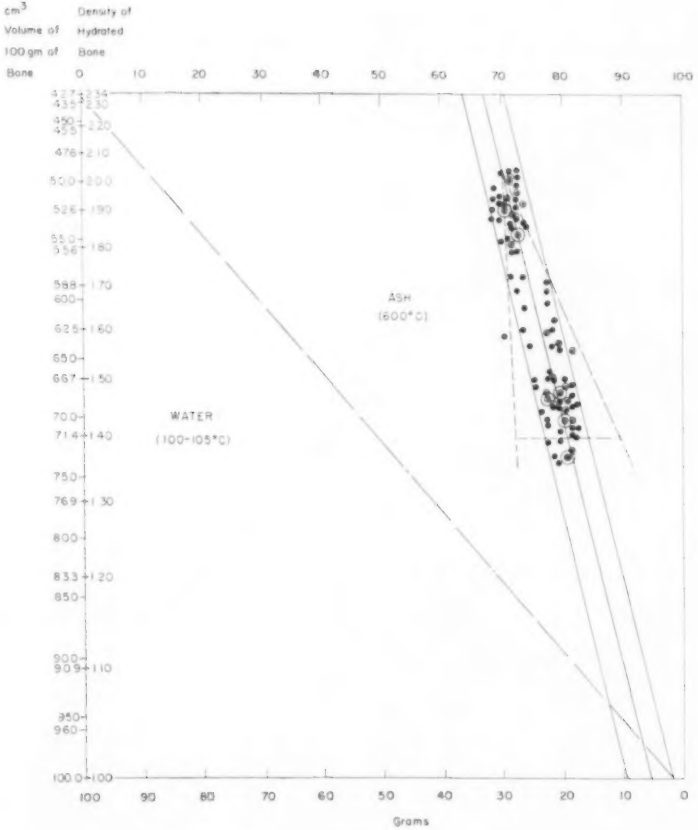
GRAPH I-B



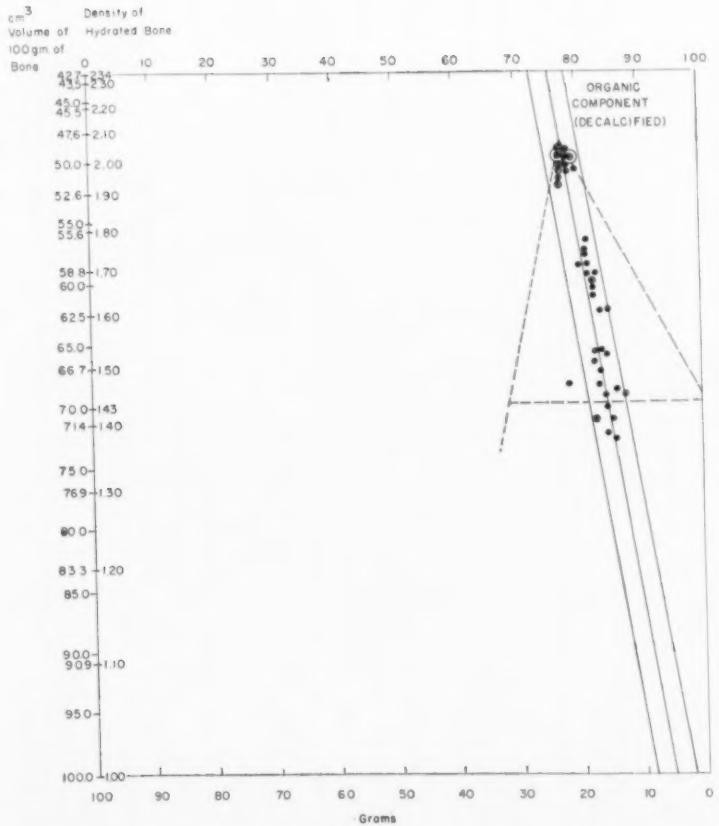
GRAPH I-A



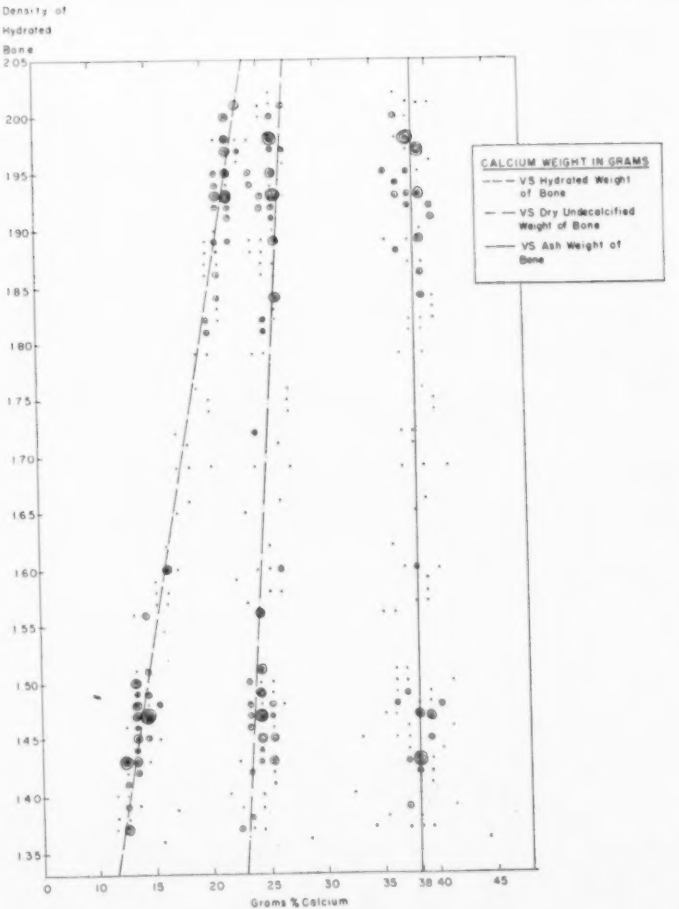
GRAPH I- C



GRAPH I- D

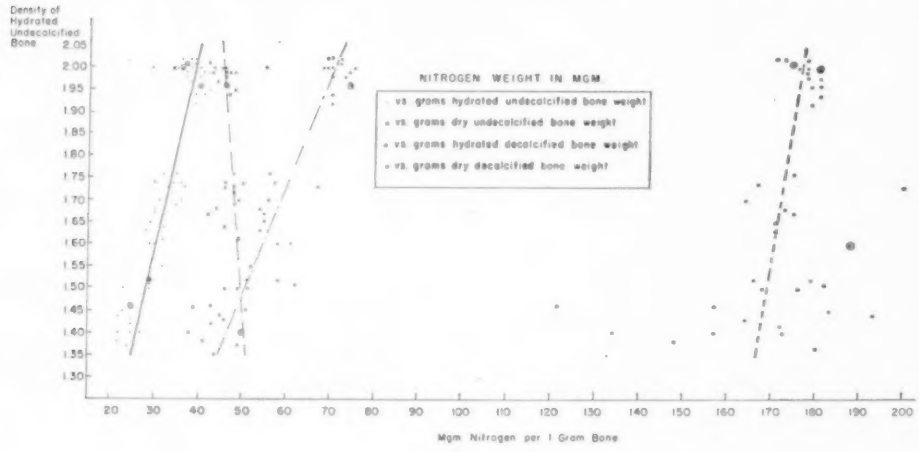


GRAPH I-E


Density of Hydrated Bone
CALCIUM WEIGHT IN GRAMS
VS Hydrated Weight of Bone
VS Dry Undecalcified Weight of Bone
VS Ash Weight of Bone
Grams % Calcium

GRAPH I-F

the specimens were white. With careful handling, seventy-nine adult bone specimens and thirty-seven puppy bone specimens did not crumble during ashing and subsequent hydration procedures. They retained the form of the original specimen. When submerged in water for hydration, trapped gas would raise the apparent volume of the piece in water and would increase the submerged volume in relation to the dry weight—thus lowering the figure obtained when calculating the density of the dry specimen. Actually, the average density of the ash obtained through the water-displacement method was 3.06, whereas the theoretical value of 3.01 [22] has been calculated for hydroxyapatite from the formula $(Ca_{10}(PO_4)_6(OH)_2)$. [It should be noted that in twenty specimens the organic matter was removed from bone samples by percolating ethylene diamine through them and that the



GRAPH I-G

density was determined by the water-displacement method. The average density of the mineral component was then found to be 3.01.] The ash samples that crumbled during manipulations were weighed and their values were calculated using the density figure 3.06.

8. Some samples were decalcified in either an 0.8 per cent or a 3.2 per cent solution of trisodium versenate* containing a phosphate buffer at neutral pH [23]. The weight and volume of hydrated bone samples decalcified in versene were obtained before drying. They were then dried at 100 to 105 degrees centigrade to constant weight in order to determine the water content of the hydrated decalcified bone matrix and its dry weight.

9. Samples of bone having a density when hydrated of 1.8 or more were extracted in a Soxhlet apparatus for twenty-four hours in a mixture of one part absolute alcohol and three parts diethyl ether. They were dried at 100 to 105 degrees centigrade in an oven to constant weight. No significant difference was found between the dry and hydrated weights before fat was extracted and the dry and rehydrated weights after fat had been extracted.

10. Calcium was determined in the ash by a modification of the method of Kramer and Tisdell [5], a suitably diluted acid solution of the ashed bone being used.

11. Nitrogen was determined both in undecalcified and decalcified bone specimens of comparable original density when hydrated by a modification of the Koch-McMeekin Micro-Kjeldahl procedure [18] for digestion and its direct nesslerization.

* Equimolar mixture of disodium versenate and sodium hydroxide. Disodium versenate [disodium salt of ethylene diamine tetra-acetic acid (dihydrate)] was obtained from Versenes Incorporated, Framingham, Massachusetts.

TABLE I

	Grams per 100 Grams Hydrated Dog Bone				Grams per 100 Cubic Centimeters Hydrated Dog Bone			
Density of Part	1.0	3.06	2.08	1.45				
Specimen Density	Water	Ash	CO_2 Space	Organic	Water	Ash	CO_2 Space	Organic
2.10	8.1	60.9	8.5	22.5	17.1	127.9	17.8	47.2
2.05	10.1	59.5	8.3	22.1	20.8	122.0	17.0	45.2
2.00	12.2	58.1	8.1	21.6	24.5	116.1	16.2	43.2
1.90	16.7	55.0	7.6	20.7	31.8	104.4	14.5	39.3
1.80	21.7	51.5	7.1	19.7	39.1	92.6	12.9	35.4
1.70	27.3	47.6	6.6	18.5	46.5	80.9	11.2	31.4
1.60	33.6	43.2	6.0	17.2	53.8	69.1	9.6	27.5
1.50	40.8	38.2	5.3	15.7	61.2	57.3	7.9	23.6
1.40	49.0	32.5	4.5	14.0	68.6	45.6	6.2	19.6
1.35	53.5	29.4	4.0	13.1	72.2	39.7	5.4	17.7
1.30	58.4	26.0	3.5	12.1	75.9	33.8	4.6	15.7

RESULTS

1. The results are presented in Graphs I-A through I-K (pages 171–177), II-A through II-D (pages 178–179), III (page 180), and IV (page 181) and Tables I and II. The lines running through data points were obtained by the method of least squares. The ordinate is the independent and the abscissa is the dependent variable for the application of the method of least squares to the data points.

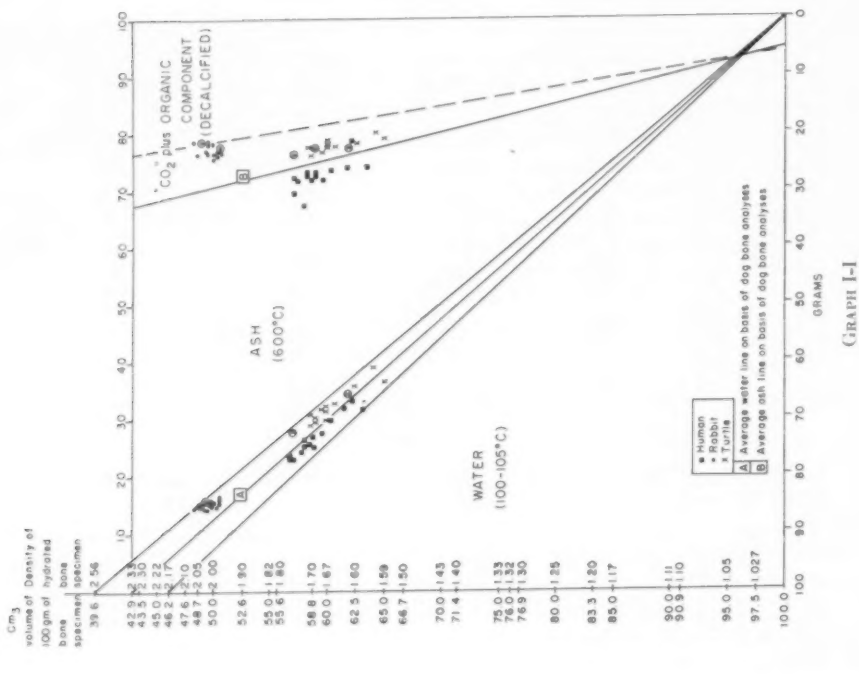
In Graphs I-A to I-E and II-A to II-D, the standard deviation is recorded as a solid line on either side of the line running through the data points. The dotted lines represent the possible error range, based on the decreasing weight of hydrated specimens in the lower-density range. The increased spread of data points in the case of hydrated bone samples having a lower density lies within the dotted lines and is considered to be due to the magnified effect of the standard weighing error of about ± one milligram in the case of small samples. It is obvious that the heavier and more dense samples from adult dogs yield more consistent individual analyses. The data points on the lines in Graphs I-A (page 171) and II-A (page 178) are numerically recorded in Table I.

2. It is possible to establish a starting point for the determination of weight, volume, and density of a fully hydrated bone sample from a dog or a puppy if the weighing procedures are carried out within twenty-four hours of the time the specimen is removed and if held at 4 degrees centigrade. The specimens may gain no weight or up to 0.1 per cent of

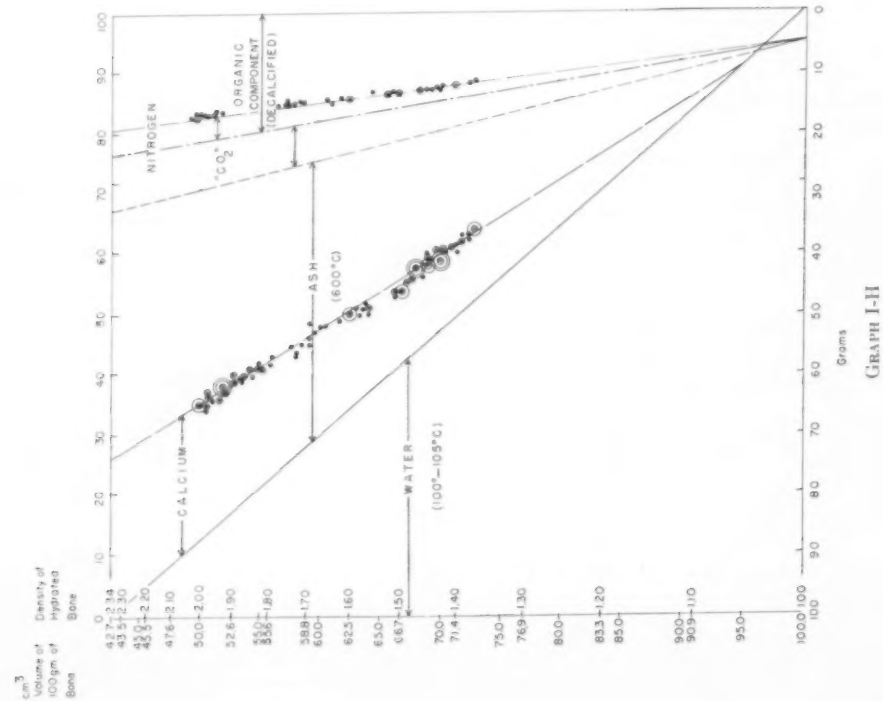
TABLE II

No. of Specimens in Group	Density Range of Hydrated Bone Specimens Prior to Drying	Average* Density of Dry Bone Specimens	
47	2.04 – 1.95	2.37 ± 1.04	2.37
45	1.94 – 1.85	2.31 ± 0.01	2.31
17	1.84 – 1.75	2.35 ± 0.07	2.35
30	1.74 – 1.65	2.37 ± 0.09	2.37
20	1.64 – 1.55	2.46 ± 0.19	2.45
41	1.54 – 1.45	2.35 ± 0.15	2.35
28	1.44 – 1.35	2.23 ± 0.14	
228	2.04 – 1.35	2.34 ± 0.13	2.36

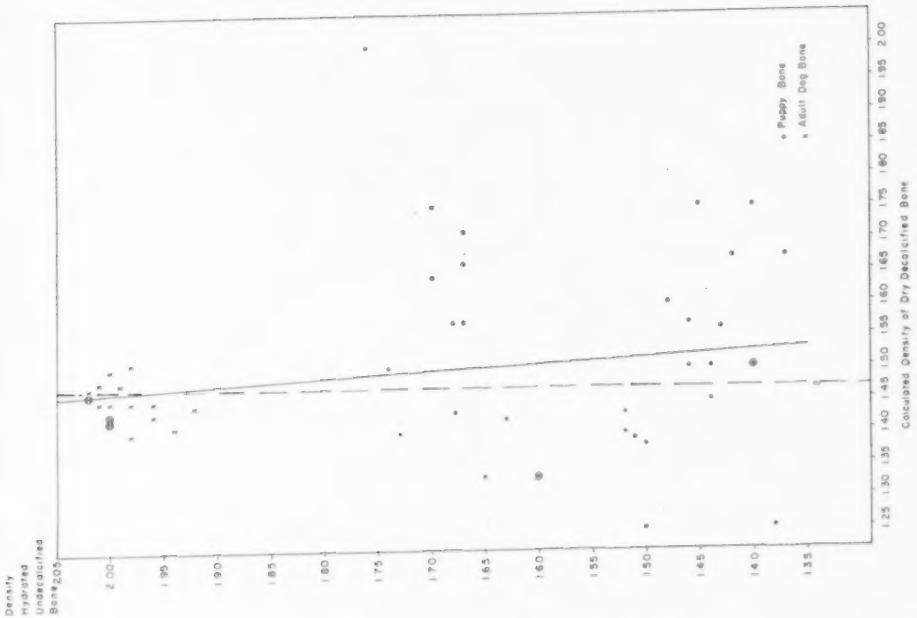
* Average figures were used for each group. Many dog samples when dry weighed less than one gram. Individual dry-density determinations are not significant to the second decimal place with the method used for determining dry density, with a possible weighing error of one milligram, unless the dry specimen weighs one gram.



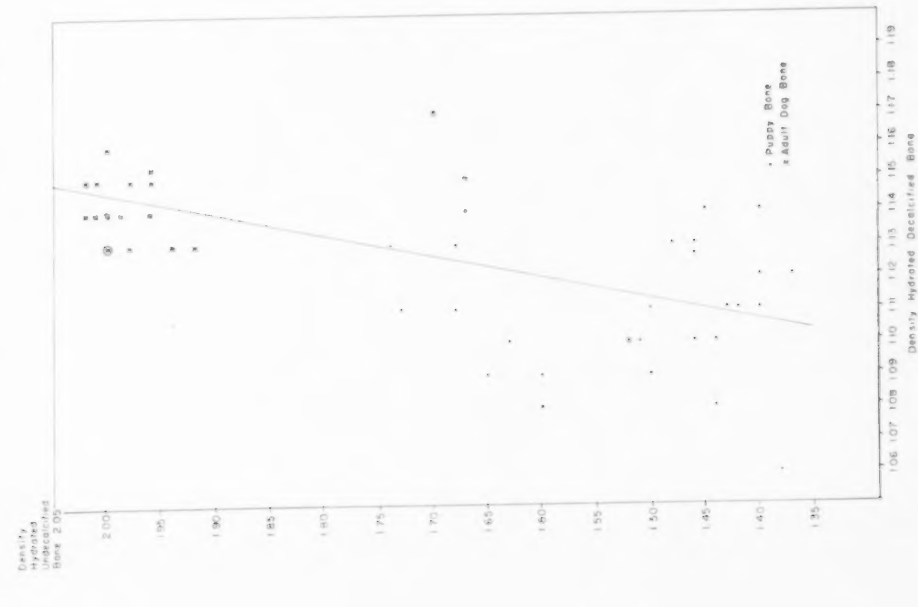
GRAPH I-I



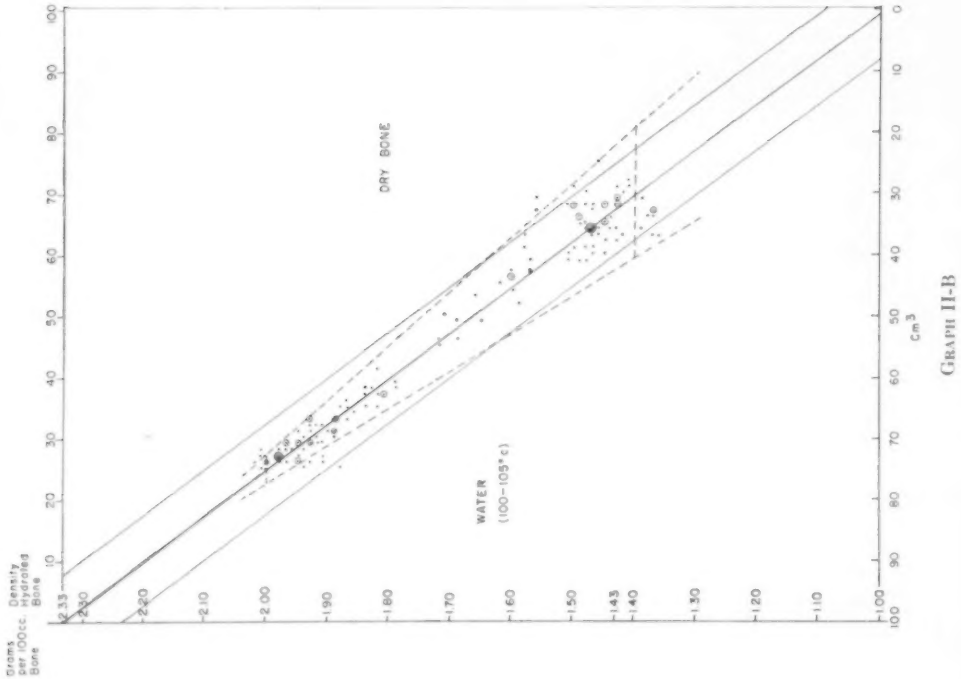
GRAPH I-II



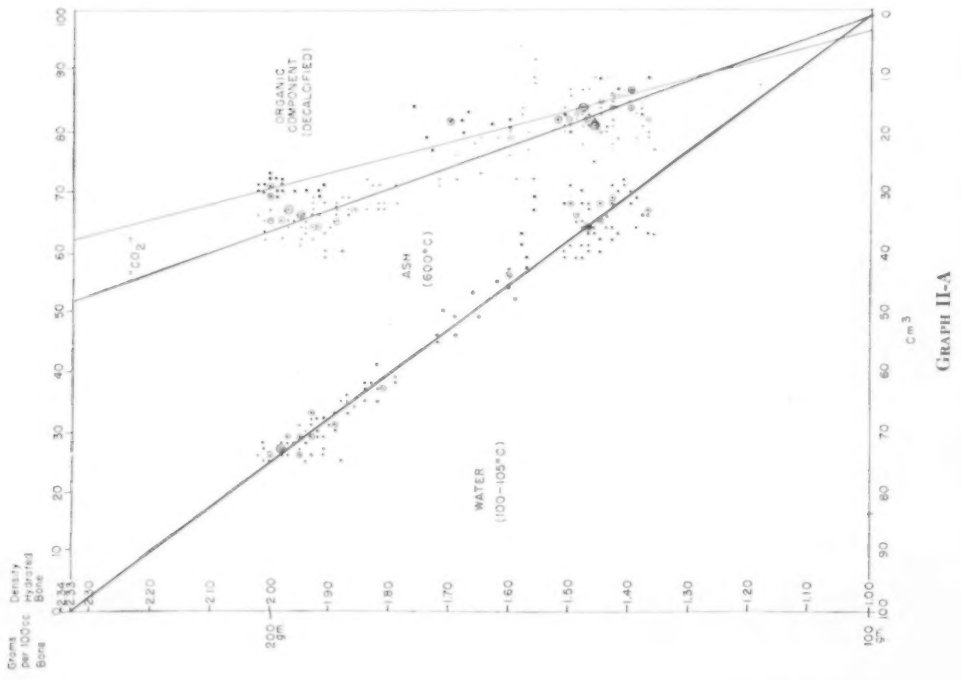
GRAPH I-K



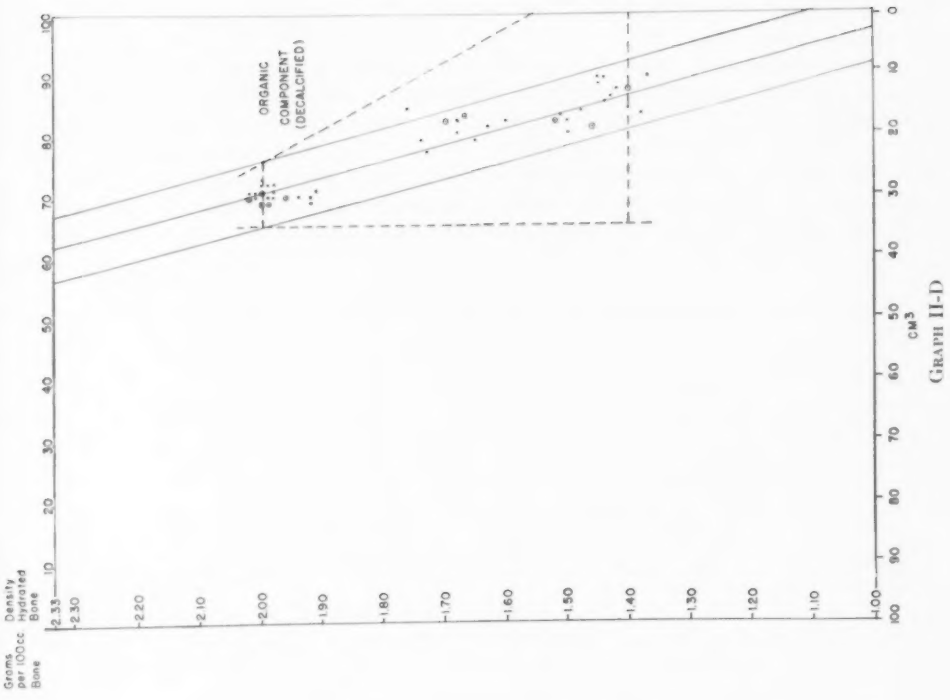
GRAPH I-J



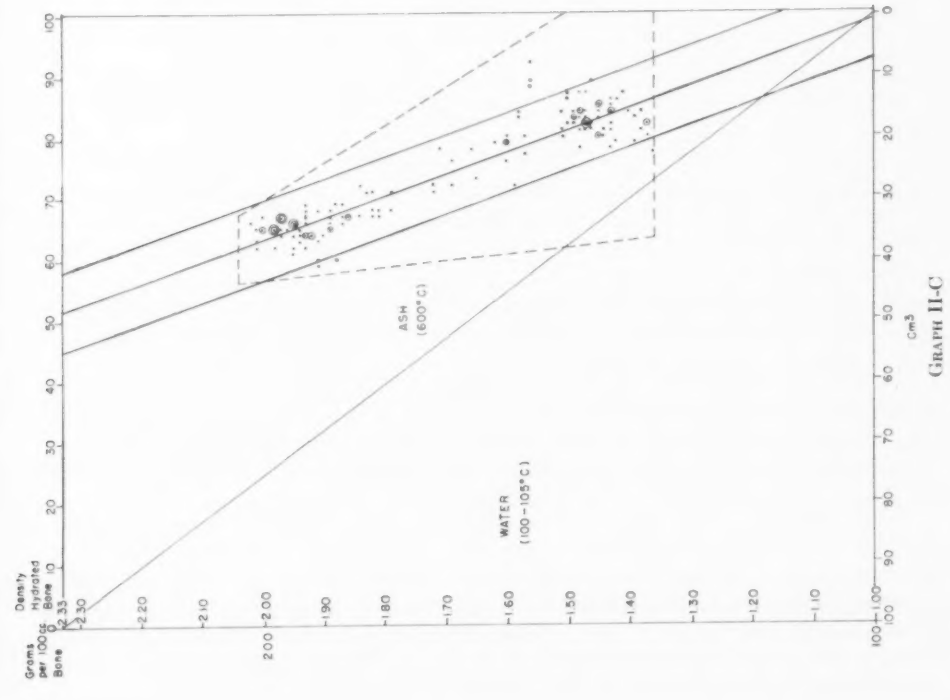
GRAPH II-B



GRAPH II-A



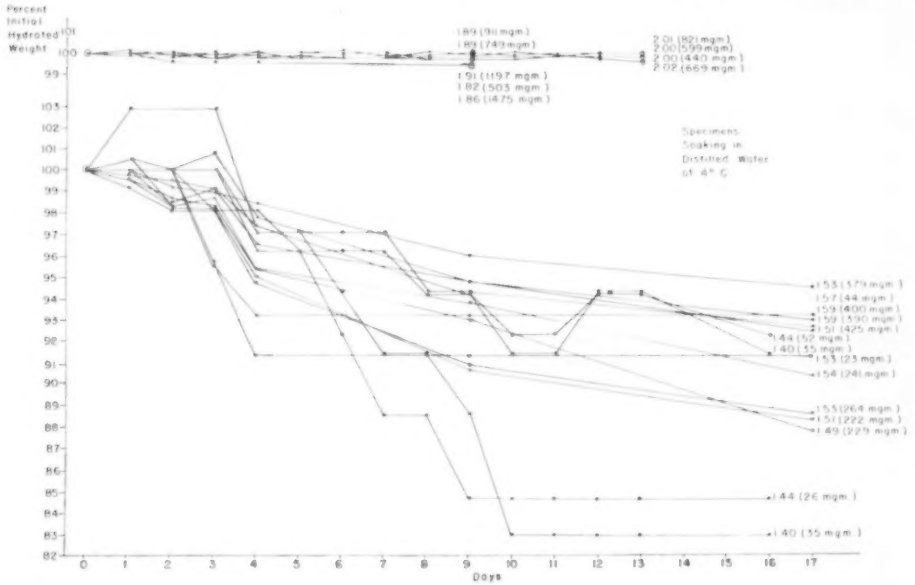
GRAPH II-D



GRAPH II-C

their moist weight in the first hour. After twenty-four hours puppy bones soaked in water lose weight (Graph III).

3. Dessication in air at room temperature over silica gel at a pressure of 225 millimeters of mercury took a longer time than drying in air at 50 degrees or 100 degrees centigrade or drying in the high vacuum of a freeze-drying apparatus without prior freezing of the bone at 0.01 millimeter of mercury. With 50 degrees drying or dessication in a low-grade vacuum (225 millimeters of mercury), constant weight was reached before as much water was removed as with drying at 100 degrees centigrade (Graph I-B, page 171). All of the methods yield results lying within the limits of standard deviation calculated



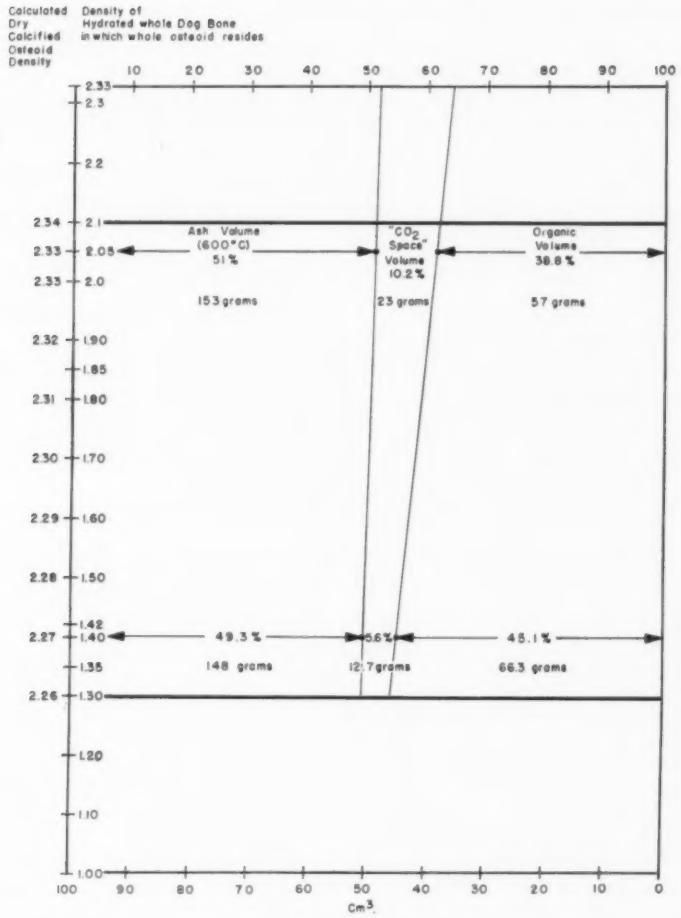
GRAPH III

for drying at 100 degrees centigrade with a weighing error of ± one milligram. Except for the line based on data from high-vacuum dessication, the slope of the lines is similar. In general bone specimens of greater thickness require a longer drying time to approach constant weight.

4. The hydrated bone from older animals had a greater density than that from younger animals. The density of hydrated canine cortical bone specimens varied from 2.01 to 1.35.

5. Density figures from individual samples of dry bone were obtained. The average density of dry tibial cortical canine bone was about 2.33 to 2.34. If individual samples weighed one gram when dry, then the dry-density figures were significant to the second decimal place However, if bone specimens, with original hydrated density above 1.45, were used, the average dry density was 2.36 (Table II, page 175).

6. Cortical bone from puppies, having original hydrated density below 1.45, had a slightly lower dry density than did the dry bone samples from adult dogs. However, the differences were small. Bones having an original hydrated density of 1.44 to 1.35 had an average dry density of 2.23. This was the only group with dry density below 2.3. In view of the fragility of these puppy bone samples, the significance of this density figure of 2.23 may be questioned. However, it is believed to show a tendency toward lesser dry density in the rapidly growing bone of newborn puppies (Table II).



GRAPH IV

7. The dry density values actually represent the relationship of the amount of ash to the amount of dry organic material in the sample. The largest single factor controlling this relationship is the degree of calcification of the osteoid in the bone sample. (Normally calcification approaches 80 per cent completeness shortly after osteoid is formed and gradually increases to full calcification thereafter[2].)

8. There was always a water compartment in the bone samples which was, in the case of the adult dog bone, never less than about 20 per cent by volume or about 10 per cent by weight. Into this water part of the analysis pattern, the organic, carbon dioxide space, and inorganic ash components never intruded. For this reason the density of hydrated whole bone never reaches the density of dry bone. In puppy bone, the water compartment was much larger than in the bone of older dogs.

9. The density of the ash (bone was ashed at 600 degrees centigrade) was 3.06, whereas the theoretical value is 3.01. In a few cases, organic matter was removed from the bone sample by percolating ethylene diamine through it; density was determined by means of the same weighing methods as were previously described. The density of the mineral compartment was then found to be 3.01. The calculated density for theoretically pure hydroxyapatite is 3.01[22].

10. The carbon dioxide space in relation to weight or volume was found by subtracting the measured sum of the ash, organic, and water components from the measured original total weight or volume of the whole hydrated bone specimen.

This space contains the carbon dioxide lost both by ashing bone at 600 degrees centigrade and, along with the bone crystals, during decalcification of the osteoid. Carbon dioxide has been found to account for 3 to 5 per cent of bone weight [21].

Some sodium and potassium and chloride are also partly lost during ashing between 600 and 700 degrees centigrade [16, 17]. Some sodium and potassium, as well as some chloride [19], may be lost during decalcification.

Some soluble organic matter is lost during decalcification and prolonged soaking of bone in water [25].

Some water of crystallization in the hydroxyapatite bone crystals, small in amount as it may be, is believed to be lost during ashing at 600 degrees centigrade [14].

Since carbon dioxide is considered to be the largest single component of this space which contains these constituents of the whole bone sample lost during ashing and decalcification, the whole space was named for the carbon dioxide. This was done with the knowledge that the compartment probably contains soluble organic matter, water of crystallization, sodium, potassium, and chloride.

The density of the dry material in this compartment could only be calculated as about 2.15 ± 0.15.

11. The density of hydrated organic matrix of nineteen samples of bone having an original density when hydrated of 1.9 or above was 1.14, and the average for thirty-two matrices from bone samples having a density when hydrated of 1.75 or below was 1.12 (Graph I-J, page 177). The over-all average was 1.13.

The average density of nineteen dry samples of organic bone matrix, obtained from bone specimens having an original density when hydrated of 1.9 or above, was 1.45. The density of thirty-two dry samples, obtained from hydrated bone specimens having a density of 1.75 or below, was 1.52. The over-all average was 1.47 (Graph I-K). Some error in the experimental method probably caused the wide divergence of data points for bone samples having a low hydrated density. For the significant density for dried bone decalcified in versene 1.45 was used (Graph I-K, page 177).

12. The ratio of calcium to ash was practically constant (Graph I-F, page 173) in all bone samples (38 per cent), and on a theoretical basis the calcium could be calculated to account by weight for 95.2 per cent of the ash as hydroxyapatite, as follows: $38 \times 2.506 = 0.952$ [22].

13. Graph I-G (page 174) is interpreted as showing that, although nitrogen appears to decrease in higher-density bone on the basis of the dry bone weight, it actually increases on the basis of the hydrated bone weight. This is explained as follows: in *dry* specimens of lower density, the organic component comprises about 5 to 6 per cent more by weight than it does in dry specimens of high density (Graph IV, page 181). On the other hand in hydrated specimens of low density the organic component is about 7 to 8 per cent less by weight than in hydrated specimens of high density (Table I, page 175).

Hydrated bone of density 2.0: organic component equals 21.4 per cent of the weight;
Dry bone of density 2.33: organic component equals 24 per cent of the weight;
Hydrated bone of density 1.40; organic component equals 14.6 per cent of the weight;
Dry bone of density 2.27: organic component equals 30 per cent of the weight.
Therefore: hydrated: $21.4 > 14.6$; dry: $24 < 30.0$.

The ratio of calcium to ash was fairly constant at 38 per cent. The ratio of nitrogen to organic component appears to increase in higher-density bone. The percentage of nitrogen in the organic component ranges from an average of about 17 per cent in specimens having an originally low density when hydrated, to about 18 per cent in specimens having an originally high hydrated density. However, the spread of data points in the lower range

may be due to systematic errors in the smaller, less dense bone samples from puppies (Graph I-G, page 174).

14. Graph IV (page 181) shows the dry-bone components grouped independently of bone water.

Average chemical analyses for bone specimens of different original densities when hydrated are found in Table I.

The density of the ash + carbon dioxide space components is found to be 2.9, the density of the organic component being 1.45. In relation to these average density figures the organic, ash, and carbon dioxide space components in Table I are treated separately in Graph IV. There appears on this basis to be a close correlation between the hydrated and dry densities of the bone specimens. However, one must realize that variations between the individual chemical analyses of bones at all levels of hydrated density were averaged, or smoothed out, by the application of the method of least squares since the straight lines through the points in the graphs were derived by the method of least squares. Points on these lines most closely fitted all of the data points, not merely at one level of hydrated density but at all the hydrated density levels. For instance if only data points for ash, carbon dioxide space, and organic components at D2, 1.95, 1.9, 1.85, and 1.8 were used to construct lines by the method of least squares, such lines would have a slightly different slope than the ones drawn to fit the data points at hydrated density levels D1.75 through 1.35. Various sequential portions of the data can thus be separately treated for bone specimens having densities when hydrated between 2.05 and 1.35. The short lines thus obtained would vary in slope from the long lines illustrated which are based on all the data points between 2.05 and 1.35.

Thus, the method used to obtain Graph IV effectively averaged, or smoothed out, variations that existed at various levels between the dry and hydrated densities. Therefore, Graph IV simply shows a *trend* toward correlation of the hydrated and dry densities in bone specimens from the same site in several normal dogs of various ages.

However, when the individual data points were analyzed in small groups between 2.04 and 1.45, at intervals 0.09 apart, the combined average dry density of these groups being 2.36, all of the individual determinations were over 2.3 and below 2.45; whereas between hydrated density levels of 1.44 and 1.35 the average dry density of such bone from newborn puppies was 2.23 with practically all of the individual determinations being over 2.1 and below 2.3. Thus, the over-all average dry density of 228 specimens is reduced to 2.33 to 2.34 from about 2.36 for the majority of the specimens. Therefore, although a trend toward correlation between hydrated and dry density is suggested in Graph IV, the actual correlation of hydrated and dry densities in individual specimens is not nearly so obvious. In fact all specimens from normal dogs and puppies, except those from newborn puppies, have a dry density averaging 2.36. In newborn puppies the dry density drops off rather sharply. However, when the data in Graph IV are separated from the hydrated density scale, the various amounts of ash, carbon dioxide space and organic components lying at each level of the *dry density scale* can be accepted as rather typical of that particular dry density. Thus, the mass of water present in a given volume of hydrated bone is not necessarily an index of the per cent calcification of the osteoid in the specimen or of its dry density. This fact should be borne in mind if the method of analysis described in this paper is applied to pathological bone.

DISCUSSION

The frame of reference for this work should be clearly noted. The data are significant only in relation to the method of cleaning, drying, decalcification, and weighing of bone specimens described. Only bone specimens from normal dogs and puppies were used. The specimens came from animals which were growing at different rates: in newborn puppies they were growing rapidly, while in adult dogs growth had ceased while the

remodelling was probably proceeding at a fixed rate. This point is significant. In the first place, the cortex of the tibia in a newborn puppy approaches the structure of cancellous bone. In an adult dog a sample of cortex contains per cubic centimeter much more calcified osteoid and is therefore described as being "dense" bone. This point will be illustrated in a following paper. Secondly, Amprino and Engstrom have shown that in newly formed bone matrix in the normal animal, the per cent calcification is less than that in long-established bone matrix. Thus both the gross and the fine structure of the bone specimens in these experiments would be expected to be undergoing parallel changes; for instance, while the specimens are becoming grossly more dense, the over-all per cent calcification should be increasing since more of the bone matrix would be of long standing. These two characteristics tended to change together in the normal canine bones used in these analyses. Nevertheless, these two characteristics (the degree of "porosity" of a bone specimen and the percentage of newly formed osteoid of lower per cent calcification in the specimen) may be mutually exclusive in abnormal bone or even in bone from some other animal than the dog. As pointed out in relation to Graph IV, correlation between hydrated and dry density is suggested by the data, but this it appears stems from the nature of the material used for analyses and the method of treating the data. It does not imply that *all* bone having a low density when hydrated must necessarily have a low dry density.

Steindler, reviewing the physical properties of bone, said that, "the specific weight of bone tissue grows in proportion to the increase of percentage of mineral substance, and it also increases in proportion as the organic substance decreases."

This concept is apparently valid only when the constituents of dry bone are considered alone, separated from water (Graph IV).

As has been pointed out, the dog bone ashed at 600 degrees centigrade can be at least 95 per cent hydroxyapatite. Hydroxyapatite crystals calcify the extracellular organic matrix of osteocytes which is called osteoid.

The organic constituent in these analyses largely represents the osteoid. This constituent, as can be seen by electron microscopy, is in turn largely collagen.

The components of the carbon dioxide space are believed to consist largely of carbon dioxide, sodium, potassium, and chloride, as well as some water-soluble organic matter. Except for the soluble organic component, these substances are thought to be associated with the surface of bone crystals. Therefore, for purposes of calculation the carbon dioxide space is considered to be part of the mineral component.

If one considers the $\frac{\text{weight per cent}}{\text{100 cubic centimeters}}$ relationships of the dry constituents of canine bone (Graph IV):

1. One can find 51 per cent ash, 10 per cent carbon dioxide space components, and 39 per cent organic matter per 100 cubic centimeters of dry bone. This material will have a density of about 2.33 and will be found if about 98 per cent of the osteoid in the specimen is fully calcified [2], as is believed to be the case in cortical bone of the tibiae of adult dogs.

2. One can find 50 per cent ash, 5 per cent carbon dioxide space components, and 45 per cent organic matter per 100 cubic centimeters of dry bone. This material will have a density of about 2.27 and will be found if the osteoid is about 75 per cent calcified, as may be the case in very young, rapidly growing puppies.

If one considers the $\frac{\text{weight}}{\text{100 grams}}$ relationships of the dry constituents of canine bone (Table I):

1. At a dry bone density of 2.33, the ash is about 66 per cent, the carbon dioxide space components about 10 per cent, and the organic matter about 24 per cent.

2. At a dry bone density of 2.27, the ash is about 65 per cent, the carbon dioxide space components about 5 per cent, and the organic matter about 30 per cent.

Only when the constituents of dry bone are considered alone, separately from water, do the mineral components appear to displace the organic matter as the ash increases. In a later paper an attempt will be made to demonstrate that even this dislocation of the organic matter by the mineral components is more apparent than real.

Actually, the variations in the proportions of the various constituents of dry samples from adult dogs and puppies are small (Graph IV). This accounts for the relatively small variation in the density of dry canine bone, which averages about 2.3. This is also believed to be the basis for the finding of Vogt and Tonsager that the ratio of ash to dry bone in human samples is almost constant (58.3 per cent ± 3.8) regardless of age. The weight ratio of ash weight to dry bone weight is a little higher (about 65 to 66 per cent) in tibial cortex of canine bone. This difference may be a species difference, the osteoid in dogs being able to hold more mineral crystals per unit volume than human bone when fully calcified. However, it could be partly due to the fact that Vogt and Tonsager used cancellous bone which has, when hydrated, a lower density than cortical bone [28] and, therefore, may have a lower density when dry than human cortical bone.

As can be seen in Table I (page 175) and in Graphs I-A (page 171) and II-A (page 178), the ash, carbon dioxide space, and organic constituents all increase in volume and in weight in whole hydrated dog bone specimens as the density of the hydrated specimens increase, at the expense of the water component.

This finding is similar to that of Hammett who found that the percentage by weight of water in the humerus and femur of rats in both sexes decreases with age and that this was largely due to an increase in ash deposition, "the increase in the percentage of organic matter being a minor factor". When only a weight basis is used, the organic increase is not so obvious as it is when a volume basis is used.

In this paper no attempt has been made to subdivide the water component. The total amount of water removed from a sample of normal dog bone is simply observed to hold an inverse relation to the density of normal hydrated dog bone. The more water removable, the less is the hydrated density. The more water removable, the less is the dry substance weight and volume which the specimen contains. In samples from which more water is removable, the ratio of ash to organic component and the ratio of ash + carbon dioxide space to organic component are slightly less.

The weight of the ash and calcium, the carbon dioxide space, and the organic and nitrogen components can be fairly well predicted for a piece of normal dog bone by simply knowing the hydrated density of the specimen (Graphs I-A and II-A) due to the similarity of the composition percentages in dry bone.

The ratio of ash + carbon dioxide space to organic component is not exactly the same for puppy and adult dog bone, but it is so similar that the density of dry dog bone varies only a little. In fact, only if the dry specimen weighs one gram can a significant dry-density difference be noted by the method employed in this work. Significant difference in density of dry dog bone occurs in the second decimal place between about 2.23 and 2.37. In general, the lower density figure is only found in bone from newborn puppies.

Since the dry bone weight and volume are largely contributed by calcified osteoid and since the mineral is twice as dense as the organic component dry density, the ratio of ash to dry weight, or the ratio of ash to organic component, or the ratio of ash + carbon dioxide space to organic component, or even the ratio of calcium to nitrogen are largely measures of degree of calcification of the osteoid in bone samples in which the medullary marrow and periosteum have been removed. It appears that these may all be a little less when found in a hydrated bone specimen of low density and a little higher than normal when the hydrated density of the bone specimen is higher, although such a relationship is not absolutely essential. In any one species there may be normal variations in degree of osteoid calcification in relation to the density of the hydrated specimen (Graph I-I, page 176).

CONCLUSIONS

1. The densities of dog bone specimens both when hydrated and dry have been reported. Although a trend toward correlation of these two characteristics appears in the material used, such correlation is not to be expected in all bone specimens.

2. The water content of the bone has been correlated with the density of the hydrated specimen.

3. The dry-substance content of the bone has been correlated with the density of the dry specimen. The mass of the dry specimen largely represents calcified osteoid. Variations in dry density represent in large part more or less complete calcification of the osteoid.

4. In specimens from normal puppies, those with a *very* low density when hydrated have a slightly lower density when dry and a slightly smaller ratio of ash + carbon dioxide space to organic component.

5. Variations in these relationships probably exist in bones from animals of different species and in disease states affecting bones of animals of any one species.

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DISCUSSION

Dr. J. Albert Key (deceased): We are prone to ignore the water content of bone, but bone is the great reservoir of calcium and an important reservoir of sodium in the body; these elements must be transported in water in order to be used elsewhere. Bone may be considered an important reservoir of water because the skeleton of a seventy-kilogram man contains from four to eight liters of water; Edelman and his associates by measurement with deuterium oxide showed that almost all of this water is exchangeable in about four hours.

Dr. Robinson and Dr. Elliott have wisely limited their studies to the compact cortical bone of dogs and have measured the water and inorganic and organic matter in this with great exactitude. The reasons for using a weight-to-volume standard are valid. They have found that the water content of cortical bone decreases with age and by volume comprises about 73 per cent in young puppies and 21 per cent in older dogs (or 54 and 10 per cent by weight). They have also emphasized the fact that the volume of a given mass of bone is constant and that if one of the three components is increased or decreased, one or both of the other must be decreased or increased, and water is the most labile component.

Bone, and this includes its water, is separated from the intercellular fluid by a layer of osteoblasts which appears to be an intact membrane. Water, electrolytes, and larger molecules must pass through this membrane in order to get from one compartment to the other. The osteoblasts undoubtedly have a considerable influence on this passage and may even secrete material in either direction in order to meet physiological or pathological needs.

Dr. Robinson and Dr. Elliott have also attempted to answer the question: where is the water in the bone and how is it held there? It may be in the collagen, the cement substance, or the inorganic crystals. They have excluded 16 per cent by volume to account for the vascular and cellular tissue of the Haversian canals which are outside of the bone, but have not attempted to account for the osteocytes which I believe form a protoplasmic syncitium throughout the bone and are on the bone side of the osteoblastic membrane. It is even possible that their processes are continuous with the osteoblasts and especially with the osteoclasts when bone is being absorbed.

Bone collagen differs from that elsewhere in the body in that when fully calcified the fibrils are encased in a sheath of apatite crystals and cannot expand or contract in length or diameter as does collagen elsewhere when it absorbs water or is dehydrated. The bone crystals appear to form first at the band areas of the collagen and as this is said to be the region where water enters the fibril, the crystal possibly seals off the fibril and then grows lengthwise to encompass it. I am not sure whether Dr. Robinson believes that the apatite crystals lie within, that is, actually impregnate, or are arranged around the collagen fibrils; but it seems to me that this arrangement can be deduced from his previous work. On the other hand, impregnation of the fibrils by apatite would help explain the observation that halisteresis does not occur, and that when bone is absorbed, the organic matrix disappears *pari passu* with the bone salts. It thus seems that the bone collagen is literally brass bound and is insulated from the bone water which is so readily exchangeable with that of the rest of the body. Consequently it is probable that relatively little of the bone water is in the collagen.

The cement substance seems to me to be a reasonable place where a good deal of water can be held since here as elsewhere it probably contains some hyaluronic acid. As this has been said to hold up to 40,000 times its weight in water, a small amount could expand or contract and imbibe or exude water without disturbing the volume occupied by the collagen or crystals.

Likewise, the crystals may be an important factor. Granted that the water of crystallization is so little that it may be neglected, still they have shown that when the organic matter is dissipated by heating to 600 degrees centigrade, the crystals can hold water equal to their volume or to one-third their weight. I do not think that it has been shown that *in vivo* the crystals are insulated from the bone water by either the cement substance or the collagen.

I would like to suggest that the properties of the organic matrix after decalcification may be quite different from those of the same material *in vivo* and that this decalcified matrix should be compared with extra-osseus collagen which has been subjected to the same treatment.

Why did they use distilled water instead of isotonic salt solution? There is no pure water in the body and immersion in this might lighten the bone.

Finally, I wish that they would study the crystal size in puppy bone and compare it with that of old bone. It is obviously not possible to separate old from young Haversian systems in a given specimen prepared for ultramicroscopic study by fragmentation, but it is possible that in old bone larger crystals might be more numerous and this might explain the rapid, almost complete, calcification of a given Haversian system by crystal growth. The tendency of young systems to absorb more radioactive calcium or phosphorus might be due to a dominance of small potentially growing crystals.

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DISCUSSION

Medullary Fixation of Forearm Fractures

(*Continued from page 98*)

synergistic action of the musculature. The result is that pronation and supination often occur at the fracture site. The presence of such shearing forces in this area is, of course, conducive to non-union.

In our present treatment of fractures of both bones of the forearm requiring open reduction, we use an intramedullary nail for the radius and a four-inch narrow slotted plate for the ulna. This permits a normal exertion of muscle forces on the radius but minimizes the shearing forces which are exerted on the ulna. Following this treatment, a plaster cylinder is maintained for twelve to sixteen weeks. This method is, of course, limited to the treatment of fractures in adults.

Fractures of the forearm are often accompanied by comminution, which may cause a loss of continuity or contact at the fracture site following reduction. Since the fragments are often small, we feel that long grafts should be inserted to overcome this deficiency. The best time to insert these grafts is following early reduction and fixation. The surgeon should not wait to see if non-union will occur.

We have used our present method of treatment in a comparatively small series, including sixty-two fractures of the radius and forty-two fractures of the ulna. Of these 104 fractures, seven were compound, and one was associated with osteomyelitis. Non-union resulted in three of the sixty-two radial fractures and in five of the forty-two ulnar fractures. In four of these eight patients, a slotted plate and a graft were subsequently inserted and union was secured. There were four persistent non-unions in the total series of 104 surgically treated fractures.

From our experience in this series we are convinced of the importance of the following basic principles: that continuity of the fracture fragments should be obtained, that supination and pronation should be controlled (thus eliminating shearing forces), that muscle compression should be permitted, and that immobilization should be maintained for twelve to sixteen weeks. The exact method used to accomplish union is not as important as the observance of these basic principles.

Atypical Myositis Ossificans

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Heterotopic ossification, or myositis ossificans, has been reported to occur in many parts of the body, sometimes adjacent to normal bone and sometimes far from it. Almost all cases, however, have been related to various types of trauma. In some cases, especially in paraplegia, the patient may recall no specific injury, but chronic unrecognized trauma may certainly be postulated. Hess, Costello and Brown, and Freiberg noted myositis ossificans following severe poliomyelitis but all of their patients had had some degree of passive exercising. The author wishes to report on four cases in which major trauma can be almost excluded and in which chronic trauma was not directly noted, although it certainly cannot be eliminated as a causative factor.

CASE 1. N. B., J. H. H. 378563. A seven-year-old colored female was admitted to the Johns Hopkins Hospital on March 10, 1946, shortly after her robe caught fire. She had about 30 per cent third-degree burns,

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. Both elbows are fused in the positions shown. The left arm is atrophied from poliomyelitis.
Fig. 1-B: Photograph showing the extent of burns.

mostly on the back and posterior aspect of the thighs (Figs. 1-A and 1-B). Her general physical condition was good except for moderate wasting and weakness of the left arm following poliomyelitis at the age of three. She had a number of skin-grafting procedures, including homeografts, until complete coverage was obtained in October 1946.

During her long hospitalization the patient lay on her stomach with her arms over her head and elbows bent. Stiffness of her elbows was noted six weeks after admission but she had no physical therapy until late in convalescence. By that time the elbows were solidly fused. Roentgenograms showed complete extra-articular bony bridges from the humerus to the ulna in both arms (Figs. 1-C and 1-D). The left atrophied arm was ankylosed at 45 degrees, the right at 90 degrees. Pronation and supination were normal bilaterally. Several years were allowed to elapse in order to permit full physical and emotional readjustment of the child and to allow the metaplasia and reaction about the new bone to become quiescent. On February 3, 1950, the bony bridge on the left was excised and part of the fibrous capsule was removed. Six months after operation the patient had a range of only 60 degrees of active and passive motion, partly because of the poor biceps and triceps motor power and partly because fibrosis of the capsule had recurred. The family asked to postpone operation on the other arm and the patient since has been lost to follow-up.

CASE 2. J. K., J. H. H. 564566. A ten-year-old girl was first seen in the Accident Room at the Johns Hopkins Hospital on February 24, 1951, fifteen minutes after igniting her dress at a gas range. She had almost 50 per cent second- and third-degree burns, mostly in the thighs and in the lower portion of the trunk (Figs. 2-A and 2-B). She had second-degree burns over most of both arms and third-degree burns mainly

FIG. 1-C

FIG. 1-D

Fig. 1-C: Roentgenogram of the left elbow, showing extra-articular ossification, with resulting bony ankylosis in 45 degrees of flexion.

Fig. 1-D: Roentgenogram of the right elbow showing a bony bridge in the general plane of the brachialis muscle.

in the right antecubital area and left finger tips, very little third-degree burning about the left elbow. She was in critical condition for weeks but obtained complete skin coverage by October 1951.

Both arms had been maintained in pressure dressing until approximately May 1951. Contractures of both elbows as well as both hips were noted several months after the burn but physical therapy could not be started until June 1951. Both hips and the right elbow responded to release of skin contractures by

FIG. 2-A

FIG. 2-B

FIG. 2-C

Figs. 2-A and 2-B: Case 2. Photographs showing the extent of burns and the position of the left elbow.
Fig. 2-C: Roentgenogram showing incomplete bony bridges both anterior and posterior to the left elbow.

FIG. 3-A

FIG. 3-B

FIG. 3-C

Fig. 3-A: Case 3. Photograph showing extent of burns and 90-degree external-rotation position of right shoulder, fibrous ankylosis of right elbow.

Fig. 3-B: Rear view of same patient showing useless position of right arm.

Fig. 3-C: Bony bridge forming ankylosis just below shoulder joint. Note absence of ectopic bone around elbow.

plastic surgery and physical therapy but the left elbow showed motion only 10 degrees above and below a right angle. The first roentgenograms of the elbow (Fig. 2-C) were made October 25, 1951; these showed mature ossification about the left elbow. Little improvement was noted even after the child had resumed normal activities. On July 22, 1954, the anterior part of the joint was freed of excess bone and scarred capsule and on August 5, 1954, the same procedure was applied in the posterior part. The child now has painless motion from 80 to 135 degrees.

CASE 3. Mrs. J. R., C. H. S. 8825. A housewife, twenty-two years old, was admitted to the Children's Hospital School on June 23, 1954, for treatment of contractures and deformities following extensive burns (Figs. 3-A and 3-B). The burns, which had occurred two and one-half years previously when her clothes had caught on fire, were mostly on the right side of the body. She had been treated at another hospital for twenty-two months with mutiple skin grafts and other appropriate procedures. When she was first seen by us, her skin was completely healed but she had extra-articular bony ankylosis of the right shoulder in 90 degrees of external rotation (Fig. 3-C) and fibrous ankylosis of the elbow in 45 degrees of flexion. Wrist and finger motion was fair. There was a 30-degree flexion contracture of the right hip and knee and 30-degree equinus deformity of the right foot, but motion of these joints in their limited range was good.

The first admission was devoted to overcoming the soft-tissue contractures and making the patient ambulatory. She was readmitted on January 14, 1955. An osteotomy of the upper end of the humerus was performed and the arm was brought into neutral rotation. The limb was held in a Haynes apparatus. After discharge the patient was able to do her own housework and engage in normal activities. The Haynes apparatus was removed on May 6, 1955, at which time bony union was solid. Function of the arm in its new position was greatly improved and scapulothoracic motion was good.

CASE 4. C. H., J. H. H. 389272. A colored man, twenty-nine years old, was seen in the Accident Room of the Johns Hopkins Hospital on September 15, 1947, after being picked up in a stuporous condition by the police. He had been hit on the head, probably in a fight. As he seemed to respond well to treatment in the Accident Room he was discharged. On September 27 he was brought back by his family because he was "acting childish" and at times was incontinent.

Physical examination was negative except for marked intellectual deterioration and memory loss. Multiple trephining was negative for subdural hematomata. The patient became more and more lethargic and gradually lapsed into coma. On October 6, 1947, fever and a stiff neck developed and a non-bacterial meningismus was diagnosed. The patient lay with his arm tightly flexed across his chest, and his hips and knees flexed. He complained at any attempt to straighten any of his extremities. He had shown no limp upon admission and had had no prior complaints about his hip. The patient gradually became more rational and his joints were held in less rigid flexion. On November 4, 1947, swelling of the left knee was noted. On November 9, 1947, orthopaedic consultation was obtained. A presumptive diagnosis of pyogenic arthritis of the knee and hip was made until x-rays (Fig. 4) showed a large deposit of immature bone around the hip joint. The

hip gradually became stiff and painless in 60 degrees of flexion; the knee regained almost normal motion. However, on walking, the patient's gait was poor and he began having back pain as a result of the marked flexion contracture of the hip. On January 27, 1952, he was admitted to the Orthopaedic Service. Since roentgenograms showed a normal appearing joint underlying the massive extra-articular ossification, an attempt to restore motion was believed to be preferable to an osteotomy. On January 31, 1952, exploration was performed. The bone was found to be situated outside the capsule and to occupy the anatomical position of the glutaeus minimus and short rotators. The fibrous capsule was fairly normal in appearance but was removed *in toto* to restore motion. The head of the femur was not dislocated. After dissection it could be moved freely and aside from moderate osteoporosis seemed normal.

The postoperative course was uncomplicated. The patient eventually achieved free flexion of from 170 to 100 degrees, 10 degrees of internal and 10 degrees of external rotation, 5 degrees of abduction and 10 degrees of adduction, and seemed pleased with the result.

FIG. 4

Case 4. Extra-articular bony mass about the left hip. The normal joint space beneath can be visualized.

About ten months after operation and seven months after full weight-bearing was begun, the patient noted a gradual onset of pain in the hip without preceding trauma. Roentgenograms showed a presumably pathological fracture of the neck of the femur with slight displacement. On October 27, 1952, a cup arthroplasty was performed as the patient refused an arthrodesis. Only 25 degrees of flexion was obtained after operation but the patient had no pain. Roentgenograms showed a return of myositis ossificans.

A definite neurological diagnosis was never made in this case. The pathological fracture presumably occurred because of interference with the blood supply following a complete capsulectomy.

DISCUSSION

It will be noted that three of these patients had severe burns. However, in one the areas of excessive ossification were not even superficially burned and in the other two the joint capsules and deep muscles were not considered to be directly damaged. In the fourth case trauma was never noted and a neurological lesion of the type causing trophic changes, as in paraplegia, was not present.

All of these patients were subjected to routine nursing care and possibly even to stretching and massage by well meaning persons. The first three cases also had numerous burn dressings applied under anaesthesia and sedation during which trauma could easily

have occurred. In all these cases the tissues evidently were in no condition biochemically or biophysically to resist even slight injury. This should serve to emphasize the importance of avoiding passive motion or even slight strain in similar cases even though normally such activities would not be considered traumatic.

The common features in these cases were relative immobility, a precarious general condition with altered protein, electrolyte, and fluid balance, and the decreased vitality of local tissues with oedema, poor circulatory flow, and possible local changes in electrolytes, pH, and proteins. Unfortunately, heterotopic ossification was not diagnosed early in any of these cases and no special studies were made. However, routine laboratory studies, as well as general experience with severe burns and prolonged coma testify to the general and local physiological changes in such cases.

It has never been proved that systemic chemical or physiological changes alone can produce heterotopic ossification. Shipley, in discussing ossifying hematoma, observed that "the systemic condition of the patient has not been observed to be significant. The lesion generally occurs in healthy well developed persons". Even in myositis ossificans progressiva no systemic changes of significance have been noted. The author concurs in this, but would like to point out that if a patient is debilitated—whether from paraplegia, poliomyelitis, or burn—physiological changes must take place locally as well as systemically. If further physiological changes occur because of local stress the debilitated patient is far less able to combat these.

Experimental causation of myositis ossificans by local trauma and irritation has long been known. Heinen and associates, working with rabbits, concluded that any agent or injury sufficient to cause proliferative repair of connective tissue can produce bone and that no osteogenic substance is necessary. Urist and McLean, working with rats, postulated an induction process in the host cells as important to ossification in abnormal locations. Mosiman, working with guinea pigs, concluded that the presence of a few live osteoblasts from pieces of living bone and periosteum was the most vital stimulant to heterotopic bone growth. These and other divergent views illustrate the difficulty of applying results of experiments in one species to another, particularly of applying results from animal experiments to man. As possibilities of experiment on human subjects are limited, we shall have to learn to deduce more from our clinical material.

It is well known that an injury resulting in bone fragmentation or periosteal stripping will tend to cause more bone formation than an injury of the soft tissues alone. It is also known that local oedema and impared circulation as found in venostasis from varicose veins or in the uninfected fibula adjacent to an osteomyelitic tibia frequently causes periosteal thickening and some new-bone formation. Moreover, trauma occurring in tissues other than bone occasionally causes soft-tissue ossification, and chronic irritation, as in a bladder or a bronchus, does occasionally produce bone. Nevertheless, we do not know why these stimuli cause bone formation in certain cases and not in others.

While any tissue of mesenchymal origin possesses the potentiality of bone formation the occurrence of heterotopic ossification is relatively rare. There must be some mechanism that initiates or triggers this reaction. Trauma is obviously the most common factor. However, the cases here presented, as well as others reported in poliomyelitis and paraplegia—especially those of myositis ossificans progressiva—indicate that obvious trauma is not the sole cause. Rare combinations of local chemical, physical, and cellular changes can produce the same result with the aid, perhaps, of mild forces which ordinarily would not be considered traumatic. If we could fully understand these changes, and produce or interrupt them at will, we would have reached another milestone in orthopaedics.

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Meniscus Lesions of the Knee in Young Children

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In January 1953, Volk and Smith reported the case of a "bucket-handle tear" of the medial meniscus in a five-year-old child, stating that this was probably the youngest patient with this injury reported in the literature. Their report, together with the generally accepted statement that meniscus injuries of the knee are very uncommon in children, prompted an investigation of the records of the James Lawrence Kernan Hospital for Crippled Children, in an effort to determine the validity of these statements. A ten-year period was chosen for study, from July 1, 1945 through June 30, 1955. Only the case records of children twelve years of age or younger were examined.

Medial meniscus tears were encountered in the case records of three children, five, ten, and twelve years of age. Lateral meniscus tears were recorded in two children nine and twelve years old. Two discoid lesions of the lateral meniscus were found in children nine and twelve years of age.

Two of the medial meniscus injuries were of the "bucket-handle" variety, and they are presented because of their rarity:

CASE 1. J.B., a five-year-old Negro girl, was initially seen in the out-patient department of the University Hospital where she was brought by a social worker who knew nothing of her background. There was a vague history of swelling of the left knee of approximately three months' duration. There was no known history of injury or of constitutional complaints. The child complained of pain in her left knee and at times in her left hip. Initial examination revealed that the left knee lacked 10 degrees of extension, but otherwise the range of motion was normal. No swelling, heat, or tenderness was noted over the knee joint. Some spasm was noted in the region of the left hip, and it was impossible for the child to extend her hip beyond 170 degrees. Roentgenograms on admission failed to reveal any abnormal conditions of the bones of the hips or the knees. The tuberculin test was negative.

Exploration through an oblique incision over the anteromedial aspect of the left knee joint revealed a classical "bucket-handle tear" of the medial meniscus, with the "handle" locked in the intercondylar notch. The entire meniscus was removed without difficulty and the patient made an uneventful recovery.

CASE 2. C.B., a ten-year-old Negro boy, had had a limp of his right leg for three months. He said that he wrenched his knee playing football three months prior to admission to the hospital, and that he noted immediate pain and inability to fully extend the right knee. The knee then began to swell. Symptoms subsided with rest. One month prior to admission he twisted the knee a second time, and on this occasion, pain and inability to fully flex or extend the knee developed. This was relieved when his father "jiggled the knee". One week prior to admission, he twisted his right ankle on a stone, causing pain in the knee and a noticeable limp. There was a loss of 10 degrees of extension. Tenderness was present over the anteromedial joint line of the knee. Roentgenograms were completely negative. The tuberculin test was negative.

The knee was explored through an oblique incision over the anteromedial aspect of the right knee joint. A "bucket-handle tear" of the medial meniscus was encountered with the "handle" portion of the tear locked in the intercondylar notch. The meniscus was removed in its entirety and the patient made an uneventful recovery.

One tear of the lateral meniscus is thought worthy of note:

CASE 3. J.A., a nine-year-old white girl, a year before examination, had run into a telegraph pole and had struck her left knee a direct blow. During the ensuing year she complained of repeated episodes of buckling of the left knee accompanied by a loud clicking and pain. Examination revealed loss of 15 degrees of flexion, atrophy of the left thigh, localized tenderness, and swelling over the lateral meniscus. Roentgenograms of both knees were negative. An arthrotomy revealed complete detachment of the lateral meniscus from its lateral and anterior attachments. The entire meniscus was lying posteriorly and toward the intercondylar notch. Excision of the meniscus led to an asymptomatic knee.

SUMMARY

Review of the operative records for a period of ten years in an active children's orthopaedic hospital revealed only seven cases of true mechanical or developmental lesions of the menisci in the knees of children twelve years of age or younger.

The average yearly number of orthopaedic operations in this hospital during the past ten years has been approximately 250. These figures show the relative infrequency of the occurrence of meniscal lesions in young children.

However, the three cases presented show that meniscal damage should always be considered as a possible diagnosis in injuries to the knees of young children.

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Giant-Cell Tumor of Cervical Vertebra with Unusual Symptoms

Report of a Case and Review of the Literature

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The following case of giant-cell tumor of the third cervical vertebra was believed to be of special interest because of the single presenting symptom of dysphagia and because of the rarity of reported cases of this tumor involving the vertebrae.

CASE REPORT

R. P., a white female, twenty-eight years old, was first seen on August 3, 1954. Three days previously she had consulted her local physician because of difficulty in swallowing of approximately six months' duration, which had slowly but progressively become more severe. Physical examination revealed a mass in the posterior portion of the pharynx, and roentgenograms revealed a destructive process in the body of the third cervical vertebra.

Two years previously the patient was said to have sustained a mild cerebral concussion in an automobile accident, but no injury to the cervical spine was apparent. One year previously she had twisted her neck while stepping from an ordinary street curb, and subsequently complained of pain and stiffness in the neck for a three-month period. She had been treated for this by a chiropractor, but no x-rays had been made. Subsequent to this she had been aware of holding her neck slightly to the right side, but had experienced no further neck pain or limitation of motion.

Following delivery of a normal child the patient began having dysphagia which became progressively more severe over a six-month period. The pregnancy, labor, and delivery had been normal. During the six-month period of symptoms, she had lost an estimated fifteen pounds in weight. She had been breast-feeding her infant during this period.

FIG. 1

Initial roentgenogram, revealing a destructive lesion of the third cervical vertebra and a soft-tissue mass protruding into the hypopharynx.

Physical examination revealed a well developed, thin, white female in no acute distress. She was afebrile and no palpable lymphadenopathy was noted. She held her head rotated and tilted slightly to the right side, but there was a full range of motion of the cervical portion of the spine in all directions without spasm of the neck muscles. The spinous process of what was believed to be the third cervical vertebra was more prominent than the next lower one, creating a "step-off" effect. Examination of the throat revealed a mass bulging into the posterior aspect of the pharynx. This was oblong in shape, measuring about five by four centimeters; its long axis was vertical and slightly to the right of the mid-line. The overlying mucosa was intact and normal in appearance. The mass was not fluctuant or tender. Except for evidence of lactation, physical examination was non-contributory.

Roentgenographic examination of the cervical portion of the spine revealed destruction of almost the entire body of the third cervical vertebra with marked posterior displacement of the remainder of this vertebra upon the fourth. A soft-tissue shadow anterior to the involved vertebral body and protruding into the hypopharynx could be seen (Fig. 1). Roentgenograms of the remainder of the skeletal system showed no abnormal findings. All laboratory findings were within normal limits.

On August 6, 1954, a transpharyngeal biopsy of the mass was performed under local anaesthesia. Gross examination revealed a solid tumor, gray in color, rather granular, and firm in consistency. Microscopic

sections (Fig. 2) revealed many large multinucleate giant cells with large vesicular nuclei. These were in a stroma containing loose fibrous tissue and fusiform cells exhibiting single nuclei similar in appearance to those of the giant cells. No mitoses were visualized, and this was therefore believed to be a rather typical benign giant-cell tumor.

The lesion was treated with deep x-irradiation, a total of 4800 r being administered through two lateral portals. There was rapid decrease in the size of the soft-tissue mass. At the termination of radiation treatment, the mass was no longer visible on examination, and the patient was able to swallow without difficulty. She had no nausea or other ill effects from the radiation therapy. She was discharged from the Hospital at the end of the course of treatment to remain in absolute recumbency with a firm roll beneath the cervical spine.

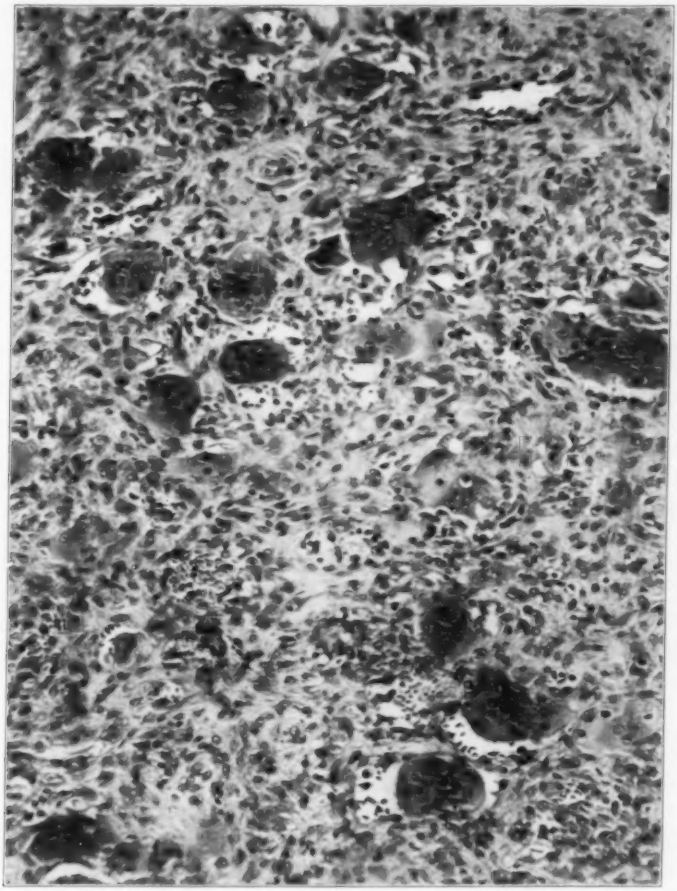

FIG. 2

Photomicrograph (× 66), revealing numerous multinucleate giant cells within a fibrous-tissue stroma.

The patient was readmitted to the Hospital on November 22, 1954, three months after radiation therapy. She had no pain or limitation of motion associated with the cervical spine and no further difficulty in swallowing. The nasopharynx appeared normal, and physical and neurological examination showed normal findings. On roentgenographic examination of the cervical spine, the soft-tissue mass was no longer visible, and the appearance of the destructive bone lesion was found to be unchanged. On November 26, 1954, a fusion operation of the cervical spine, extending from the second through the fifth cervical vertebra, was performed, autogenous cancellous bone chips from the iliac crest being used. The postoperative course was uneventful and the patient was discharged from the Hospital on December 8, 1954, to continue bed rest for six months. No external fixation was used during this period of recumbency.

FIG. 3

FIG. 4

Fig. 3: Roentgenogram made in March 1955, showing absence of the soft-tissue mass and proliferation of bone at the site of previous destruction in the body of the third cervical vertebra.

Fig. 4: Roentgenogram made October 21, 1955, fourteen months after radiation therapy and eleven months after fusion operation, showing both anterior and posterior fusion.

When the patient was seen in March 1955, she was noted to have normal rotational motion of the cervical spine. She had no pain in the cervical region and had had no dysphagia. Roentgenograms revealed proliferation of bone along the anterior margins of the bodies of the second, third, and fourth cervical vertebrae, as well as in the region of the laminae and spinous processes at the site of the fusion (Fig. 3). The patient was allowed to be ambulatory with use of a Thomas collar for external support.

Roentgenograms made on October 21, 1955, eleven months after operation, revealed complete anterior and posterior fusion of the involved vertebra to the adjacent vertebrae and there was no evidence of an active destructive process (Fig. 4). The patient is engaged in normal activity; she has no symptoms and uses no external supportive measures for her neck.

On the basis of the microscopic evidence it was felt that there was no question but that this was a benign tumor which would fall into Group I as defined by Jaffe, Lichtenstein, and Portis. The incidence of malignant growth of this tumor is stated by most authors to be between 5 and 10 per cent, although some[10] do not agree that it is a true neoplasm or that it has a malignant form. Meyerding[18] reported that 19 per cent of the tumors in his series from the Mayo Clinic were malignant.

DISCUSSION

There is much controversy in the literature regarding the merits of surgery as against radiation therapy in treatment of this lesion. Many authors[2,4,9,12,14,21,24] advocate the use of radiation therapy. Some of the advantages cited are that the capsule of the tumor is left intact, that the response to radiation is as rapid as to surgical treatment and loss of function is less, that treatment is painless and the risk of operative infection is absent, and that the rate of cure is as high as that in surgical treatment. On the other hand, Cahan and his associates point out that later sarcomatous changes may appear not only in involved but in irradiated normal bone. They cite eleven cases in which such changes occurred following irradiation therapy for giant-cell tumors in various locations. Other disadvantages of irradiation treatment are the possibilities of incomplete cure, danger of overdosage, and the effect on growing epiphyses in the younger patients.

Many other writers have strongly advocated surgical treatment[7,10,23]. Meyerding[18,19] pointed out that while curettement and packing with bone chips is usually the treatment

desirable for lesions which are surgically accessible, in certain sites such as the ribs, ulna, radius, or fibula regional resection of the involved bone and replacement is the treatment of choice. Kolodny has estimated that the recurrence rate after curettage of these lesions is about 20 per cent. Surgery combined with irradiation therapy has almost uniformly been reported to give less favorable results than either used alone. This may be due to the fact that this type of treatment was used in cases in which the prognosis was unfavorable from the onset.

In view of present knowledge concerning this tumor, improved operating techniques, and availability of modern chemotherapeutic agents to control infection, the trend is toward surgical treatment. However, because the lesion in our case was not accessible surgically, it was deemed advisable to treat this patient with x-irradiation. Fusion was later performed to provide added stability.

Review of the literature reveals that giant-cell tumor is a relatively rare neoplasm and that the vertebral column is an unusual location for this tumor. In the numerically significant series of giant-cell tumors reported in the literature, it was found that of approximately 1,000 cases there were a total of twenty in the sacrum and forty-nine in the vertebrae; only four of the latter were in the cervical portion of the spine. However, these figures are not altogether reliable, as the authors in question[5,6,7,8,10,15,18,20,21,24] freely borrowed cases from each other without stating the source of their case material. Dean Lewis, in 1924, reported a single case of giant-cell tumor in the body of the fourth thoracic vertebra. In reviewing the literature he found sixteen previously reported cases involving the vertebrae. Only one of these was in the cervical portion of the spine; it involved the lateral parts of the third and fourth cervical vertebrae. This was reported by Madelung in 1907 but his histological description was so vague that it is not possible to say definitely whether his was a true case of benign giant-cell tumor. Simmons, reporting on all cases in the Registry of Bone and Joint Sarcoma prior to 1925, found 116 cases of giant-cell tumor, of which four were in the vertebrae and one in the sacrum.

In addition to the above-mentioned cases, four case reports of giant-cell tumors involving the vertebrae were encountered in the literature after 1925. MacFarlane and Linell in 1934 reported on a case in which the body of the third cervical vertebra was involved; the presenting symptom was pain due to a pathological fracture. Hamsa and Campbell in 1953 reported a case in a six-year-old female involving the first sacral vertebra and a case in a fourteen-year-old female involving the twelfth thoracic vertebra. Each of these was treated with x-irradiation; however, in the second case there was progressive collapse of the affected vertebral body and a spine fusion was performed. In January 1955, Bowman and Reals reported a case involving the spine of the sixth cervical vertebra, the presenting symptom of which was pain. This brings to seven the total number of previously reported cases involving the cervical spine although, by present-day diagnostic criteria, they are not all well enough documented to allow us to be certain of the diagnosis.

Although by no means statistically significant, the youthful age of the patients with involvement of the spine is striking. In the majority of cases the body of the vertebra is involved, as stated by Geschickter and Copeland in their mention of Lewis' report. They also noted that only the bones of cartilaginous origin are involved. Almost invariably the presenting symptom in giant-cell tumor has been pain, usually associated with a pathological fracture. We believe the absence of pain and the presence of normal function of the affected part in this patient to be most unusual, and the presence of the retropharyngeal mass with resulting dysphagia to be unique.

Two sources of misconception as to the available statistics on this condition must be borne in mind. First, we must remember that much of the confusion which formerly existed as to what comprises a giant-cell tumor still exists to some extent, so that many cases which have been diagnosed as giant-cell tumor do not actually belong under this classification. This is demonstrated by the fact that Jaffe, Lichtenstein, and Portis, in

reviewing the twenty-eight cases classified as giant-cell tumor at the Hospital for Joint Diseases, found only fourteen which actually would be so classified according to present-day criteria. The rarity of this tumor is illustrated by the fact that review of the cases at the Campbell Clinic[23] over a twenty-year period revealed that only forty-one actual cases of giant-cell tumor were encountered as compared to 211 cases of sarcoma of bone for the same period. The second source of error lies in the fact that the same cases may well be reported in more than one series.

Therefore, we find that on the basis of the cases reported in the literature the incidence of giant-cell tumor in vertebrae is rare, particularly in the cervical region. It is the rarity of this condition in the cervical vertebrae, together with the unusual symptoms, which makes this case of special interest.

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Bilateral Undescended Scapula Associated With Omovertebral Bone

Report of a Case

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Many articles have been written on the condition variously termed Sprengel's deformity, congenital elevation of the scapula, and undescended scapula. These articles describe the frequent association of this condition with unilateral or bilateral omovertebral bones and with anomalies of the cervical spine.

The case reported here is of interest because, although the condition was bilateral and was associated with bilateral and unusually well developed omovertebral bones and with an anomaly of the cervical spine, there was almost no loss of normal useful function.

A nineteen-year-old colored male was referred to the Orthopaedic Clinic by the Armed Forces Examining Station for opinion as to his fitness for military service. He had presented himself as a volunteer for enlistment. He was the only child of the union of his father and mother but had a step-brother and step-sister of his father and a different mother, and a step-sister of his mother and a different father, both parents having been married previously. No known congenital anomalies existed in the family of either parent. His deformity had been present since birth, but he had been otherwise well and healthy, experiencing only the usual diseases of childhood. He had never considered his deformity a physical handicap and had indulged in many grade and high-school athletics. He played football with no difficulty, could make two-arm overhead shots in basketball, and could pole vault with as much facility as any of his companions. He had been graduated from high school at the age of eighteen. During summers and weekends he had held odd jobs as golf caddy, supermarket porter, car washer, and restaurant bus boy.

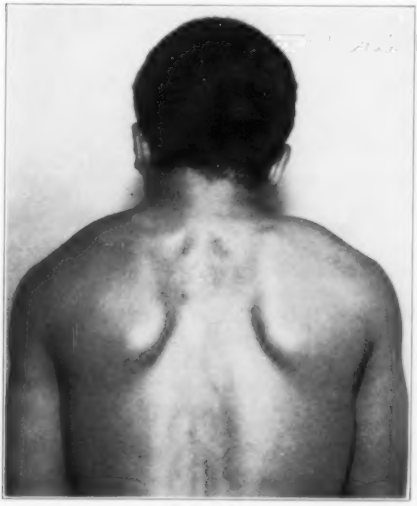

Fig. 1-A

Fig. 1-B

Fig. 1-A: Patient standing relaxed. The lower portions of the bilateral omovertebral bones can be seen bulging under the skin. (United States Army photograph, taken by the Medical Illustration Section, Clinical Photography Laboratory, Letterman Army Hospital, San Francisco, California.)

Fig. 1-B: Patient with arms extended forward. The movement of the scapulae away from the omovertebral bones is apparent; the distal ends of the bones are bulging more prominently under the skin. (United States Army photograph, taken by the Medical Illustration Section, Clinical Photography Laboratory, Letterman Army Hospital, San Francisco, California.)

The applicant was an intelligent and alert young male of slight stature and build. He appeared to be well adapted to his deformity from a psychological standpoint, relating, without apparent bitterness, how he had been called "Humpy" and various other nicknames all his life. He gave the impression of some compulsion to prove to friends, family, and himself that he was as capable as any to perform useful military service, which, perhaps, accounted for his volunteering for enlistment rather than waiting to be drafted.

The deformity resulting from the bilateral elevated scapulae was apparent and typical. His general muscular development was excellent and all muscles about the shoulder girdle, neck, and upper portion of the back (including the rhomboidei and the trapezius) were present and of excellent strength. The usual alteration in the shape of the scapulae, including the hooking forward of the upper margins, was also present. Motions of both upper extremities at the shoulders were normal, except for a slight decrease in abduction, and could be carried out simultaneously and with equal facility. The position of the neck did not need to be altered in any way to permit either single or simultaneous upper-extremity movements. The forward and

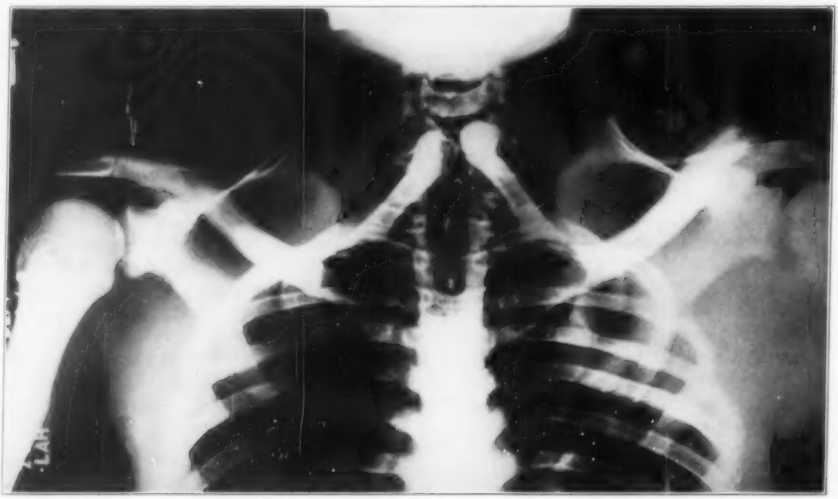

FIG. 2

Anteroposterior roentgenogram. Both scapulae are elevated and the bilateral omovertebral bones are connected with the laminae of the fifth and sixth cervical vertebrae proximally but have no bone union with the scapulae. (United States Army photograph, taken by the Medical Illustration Section, Clinical Photography Laboratory, Letterman Army Hospital, San Francisco, California.)

backward bending range of the head and cervical spine were normal, but rotation was limited to 45 degrees, both right and left, and lateral bending to 35 degrees, both right and left.

The omovertebral bones lay just under the skin and were easily palpable. Each felt like a well formed, slender shaft-type bone with slightly enlarged rounded ends. The distal ends lay at about the middle of the vertebral borders of the scapulae when the patient stood relaxed, and the proximal ends lay side by side at the level of the spinous processes of the fifth and sixth cervical vertebrae. Upon abduction, forward extension, and elevation of the arms, the vertebral borders of the scapulae could be felt to move, this movement separating them from the distal ends of the omovertebral bones. In Figures 1-A and 1-B an attempt has been made, by means of highlighting, to show the omovertebral bones with the arms in the neutral (Fig. 1-A) and forward-extended (Fig. 1-B) positions. The vertebral borders of the scapulae had palpable concavities which appeared to represent the portions of the borders which moved about the distal ends of the omovertebral bones during scapular movement.

Roentgenographic examination demonstrated anomalies of both shoulder girdles and of the cervical spine. The right scapula was elevated, and its supraspinatous portion was curved anteriorly in a manner characteristic of Sprengel's deformity (Figs. 2 and 3). The vertebral border of the scapula was irregularly convex with a shallow concavity in its mid-portion where it adjoined a well developed omovertebral bone. These two structures were separated by a distance of approximately 1.5 centimeters and fluoroscopic examination demonstrated that there was a considerable degree of mobility in this region. The proximal end of the right omovertebral bone was flared and attached to the laminae of the fifth and sixth cervical vertebrae. A narrow cleft was noted in the neural arch at this level.

Similar changes were present on the left side except that the proximal end of the omovertebral bone was attached primarily to the arch of the fifth cervical vertebra. The cervical spine showed an additional

anomaly consisting in posterior displacement of the odontoid process of the second cervical vertebra in relation to the anterior arch of the first cervical vertebra, with resultant narrowing of the spinal canal at this level (Fig. 4).

ORIGIN OF THE OMOVERTEBRAL BONE

A majority of authors support the view that Sprengel's deformity is caused by a failure of the scapula to descend during embryonic development. On the other hand, perusal of the literature reveals no predominance of opinion relative to the origin of the omovertebral bone. Varied findings have been reported and varying theories postulated, the resulting impression being that many authors have premised their favored theory on the anatomical findings in a particular case or cases.

FIG. 3

Fig. 3: Tangential roentgenogram of scapula showing the anterior angulation of the superior margin of the scapula and coracoid process (upper arrow) and the omovertebral bone (lower arrow). (United States Army photograph, taken by the Medical Illustration Section, Clinical Photography Laboratory, Letterman Army Hospital, San Francisco, California.)

FIG. 4

Fig. 4: Lateral roentgenogram. Note the elevation of the shoulders and the anterior displacement of the first cervical vertebra on the second, resulting in encroaching of the odontoid process on the spinal canal. (United States Army photograph, taken by the Medical Illustration Section, Clinical Photography Laboratory, Letterman Army Hospital, San Francisco, California.)

In 1880, Willett and Walsham reported that a postmortem dissection had revealed findings of a high left scapula associated with segmental aberrations of the vertebrae and ribs and with a bridge-like bone ankylosed to the posterior border of the scapular and to the spinous process of the sixth cervical vertebra. They postulated that the bridge-like bone (1) represented a process formed from the vertebra or (2) was a scapular element similar to the suprascapula of the thornback skate or (3) had developed independently of both the spine and scapula. In support of the third alternative, they theorized that the bone either was an ossified intermuscular plane or represented a rudimentary scapula which had been produced when the embryo had been cleft into right and left halves, the final atomical structure resulting from various fusions and suppressions.

In 1883, the same authors reported a second case. In this case the bone structure had an osseous attachment to the spines of the seventh cervical and first thoracic vertebrae and was connected by a layer of cartilage to the scapula. The authors regarded the deformity seen in these cases as the result of overdevelopment of the normal epiphysis along the posterior border of the scapula and "consequently, as the homologue of the suprascapular bone of the lower vertebrata". They did not consider it as an exostosis from the spine or as a mere overgrowth of the scapula but felt that it had been present from the time of the differentiation of the cartilaginous shoulder girdle from the mesoderm. It is of interest to note that, at this early date, one of the discussers of their paper objected to this "reversion" theory, disagreeing with the implication that mammals descend from fishes.

In 1891, Sprengel published his notable article on the scapular deformity but made no mention of the omovertebral bone. In the same journal in the same year, however, Kölliker described two cases of this deformity in which he had found an exostosis arising from the medial border of the scapula. He postulated that the exostosis had arisen from the cartilaginous medial border, which has its own ossification center.

In 1894, in a report to the Pathological Society of London, Hutchinson presented the case of a child with a high left shoulder. To quote the report, "The laminae of the third, fourth, fifth, and sixth cervical vertebrae did not meet in the middle line, and were fused on the left side; from the fused mass there proceeded outwards a plate of bone terminating in a process of cartilage, with which the scapula articulated by its upper and inner angle. This disposition disproved the possible view that the osseous process was an abnormal development of a suprascapular element. . . . Although in certain fishes a suprascapula element articulated with one or two of the upper dorsal vertebrae, Mr. Hutchinson was not inclined to regard the specimen as one of reversion to a previous type."

In 1895, Kölliker revoked his original concept of the deformity (presented in 1891) and reported two further cases in which he had performed operations and which had convinced him that what he had previously called an exostosis was a normal forward extension of the upper margin of the scapula.

In 1908, Putti described a case in which the omovertebral bone was connected with the scapula by a strong ligament, which permitted free motion. It was attached to the transverse process of the sixth cervical hemivertebra by cartilage. In discussing the origin of this deformity, he cited the case of Hutchinson and questioned whether such a bone, if it did originate from the scapula, could fork into four bone processes connecting with four consecutive vertebrae as had occurred in his case. He denied that there was any connection between human beings and fishes or amphibians, there being no intermediate structures between the lower and higher forms. It was his conclusion that the omovertebral structure is a costiform bone arising from vertebral elements during the segmentation process.

In 1908, Horwitz summarized 136 cases of Sprengel's deformity obtained from the literature and other sources. In a section titled "Exostoses and Articulations", he stated that 25 per cent of the patients had a bony, fibrous, or cartilaginous attachment of the scapula to the vertebral column. He cited the opinion of Dr. Charles S. Minot that the scapula develops as a mesodermal sheet which is continuous with the vertebral sheet and that separate centers of ossification can appear between these two points and become transformed into a continuous band of bone. Horwitz favored this theory of the origin of the omovertebral bone.

In the fourth edition of his text published in 1921, Keith stated that the descent of the embryonic arm from the cervical to the final position over the ribs (which normally occurs in the third month) may be arrested, this delay often being accompanied by "irregularities in the formation of the cervical vertebrae . . . and the appearance of a skeletal element of the shoulder girdle which is present in certain fishes (Dipnoi and Selachii).

. . . In fishes this bone joins the suprascapula to the occiput; when it appears in man it is usually fixed to or articulates with the spinous process of the lower cervical vertebrae."

In 1927, Jackson described one case and presented an extensive review of the literature. His perusal of 112 references led him to discount the theory that the omovertebral bone originates from the scapula and to feel that the bone is probably a displaced cervical rib and is certainly of costal origin.

In 1941, Smith cited Willett and Walsham and their discussions with Parker, an authority on the comparative anatomy of the shoulder girdle. Parker felt that the omovertebral bone resembles the suprascapular bone of some of the lower vertebrates. In the frog and toad the suprascapular bone is a large osseous, dorsal appendage to the scapula and is not united to the vertebral column. In the thornback skate it is firmly united to both the vertebral column and the scapula, constituting a rigid pectoral girdle. In man and in other higher vertebrates, this bone is represented by the epiphysis at the vertebral border of the scapula. In his study of fifty cases of Sprengel's deformity, Smith found a connection between the high scapula and the vertebrae in fourteen patients. The connection was an osseous structure in eleven patients and a fibrous band in three, the former being joined to the scapula by cartilage in ten patients and by a true joint in one and to the cervical spinous processes and laminae by cartilage or by complete bone union. Smith concluded that "The omovertebral structure . . . is a homologue of the suprascapular bone which is found in several of the lower vertebrates."

In 1943, Engel presented an intriguing theory concerning the etiology of the undescended scapula and related syndromes, explaining them on the basis of "bleb" formation. He described the migration in the embryo of cerebrospinal fluid through the area membranacea at the roof of the fourth ventricle to form the subarachnoid space. If some factor allows undue escape of the fluid, it migrates into the subcutis area of the adjacent neck region and produces subcutaneous blebs which exert deleterious effects by means of pressure and inflammatory reaction. This bleb formation in the neck region occurs during the fifth to sixth embryonic weeks, the period during which the scapula is still at the level of the fourth cervical to the the first thoracic vertebra. This is also the period during which the limb bud appears, which explains the combinations of anomalies of the scapula and upper extremity.

In 1952, Jeannopoulos reported thirty-five cases of elevation of the scapula, in twenty-one of which an operation had been done. He had found an omovertebral bone in eleven of the cases and had performed excision in ten. He characterized the omovertebral bone as "a roughly trapezoid or wedge-shaped chondro-osseous structure, the narrow extremity of which was continuous with a spinous process, lamina, or transverse process of one or more of the lower cervical vertebrae". In one case the apex of the bone was globular and covered with hyaline cartilage and articulated with the cervical spinous process as an enarthrodial joint. The mode of attachment of the scapula to the vertebral border varied in the ten cases in which excision had been done. There was bony continuity in one, cartilaginous union in three, a true joint in one, and a pseudarthrosis in one; in the other four the bone bar was short or incomplete and the free cartilaginous extremity was attached to the scapula by a fibrous band. He stated that he had found a rigid pectoral girdle, such as is found in the thornback skate, in three patients, but he felt that his aggregate findings did not substantiate the theory that the omovertebral bone originates from the scapula. He cited the observations of Maffei, in 1923, and Schrock, in 1931, that congenital elevation of the scapula does not exist without lesions of the cervical or thoracic vertebrae or of the thoracic cage and stated that his own series confirmed this observation.

DISCUSSION

This case was felt to be of particular interest because of the essentially normal function which the patient had despite the presence of bilateral elevated scapulae and bilateral

well developed omovertebral bones. The usual clinical finding is that the omovertebral bones limit scapular and upper-extremity motion, movement of the head and neck away from the involved side being often necessary to permit abduction of the arm. This patient had never noticed such limitations and had enjoyed the normal athletic activities of youth.

When the scapulae were moved, the concavities on their vertebral borders moved about the distal ends of the omovertebral bones, as was shown by both palpation and fluoroscopy. This would lead to the assumption that this movement had always been present and that its continuance during growth and ossification had produced the scalloped-out concavities on the borders by means of pressure effects.

An unusual and interesting associated anomaly of the cervical spine found in this case was the central location of the odontoid process in the ring of the atlas. As a result of this anomaly it would seem that the spinal cord would occupy considerably less space than normal and that it would be in constant jeopardy. No injury to the spinal cord was observed, however. Numerous roentgenographic studies revealed no abnormal mobility in this area and there was no history of an injury which could have produced the condition traumatically, indicating that the condition represented a congenital abnormality. Since the patient has taken part in football and in other contact athletics, it can only be stated that either the situation in this region is entirely stable or that he has been extremely lucky in not damaging his cervical cord.

Discussion of our case has raised the question whether the two bones could properly be termed omovertebral bones, since they do not appear to articulate with the scapulae. Although the bones were not exposed surgically, we, nevertheless, believe that they do fulfill the necessary criteria, for we feel that they probably have a fibrous connection with the scapulae such as has been described by Putti, Horwitz, Smith, and Jeannopoulos. The anomaly of the cervical spine found in our case appears to conform to the predominant opinion that such abnormalities are almost always found in association with congenital elevation of the scapula.

We have been informed that the patient was accepted into the Army, but we have not been able to learn how well he has been able to get along in military service.

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Chronic Sporotrichal Synovitis of the Knee

BY FREDERICK S. WEBSTER, M.D., AND DUANE WILLANDER, M.D., LINCOLN, NEBRASKA

Little has appeared in the literature describing the bone and joint manifestations of sporotrichosis, which is generally thought to be a skin infection. The disease was first described by Link in 1809, and Schenck, in 1898, was the first to isolate the fungus, *Sporotrichum scheneckii*, and to prove its etiological relationship.

Sporotrichosis has been reported in thirty of the forty-eight states in this country. Various types of the sporotrichum fungus have been described. Of these, the *Sporotrichum schenckii* is the most important clinically. It is a frequent saprophyte on various kinds of vegetation. Microscopic examination of a direct smear shows cigar-shaped cells, and when

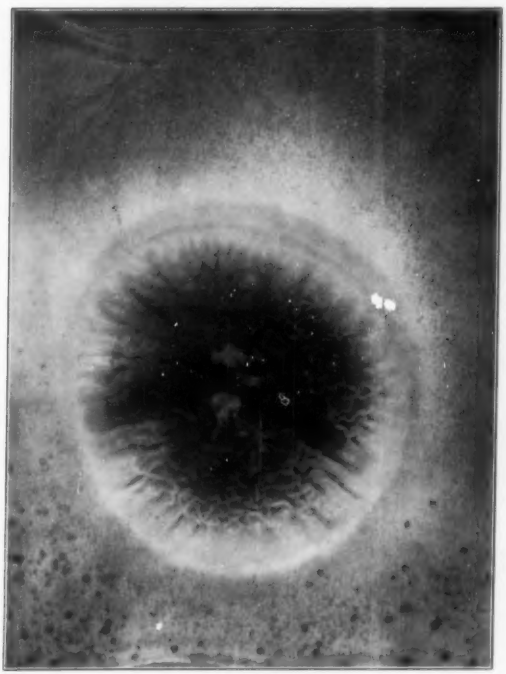

FIG. 1-A

FIG. 1-B

Figs. 1-A and 1-B: Colonies of *Sporotrichum schenckii* cultured on Sabouraud's media.

cultured on dextrose agar and on Sabouraud's media, it forms a jet black colony which, on repeated subculture, may change in color to brown, tan, or cream (Figs. 1-A, 1-B, and 1-C).

The mycelium is profuse, fine, and branching. Pear-shaped conidia are present at irregular intervals along the course of the mycelium, and these also appear as terminal triads or tetrads (Fig. 2).

Clinically, there are six types of sporotrichosis. The one most frequently encountered is the localized lymphatic type with the typical primary chancre and cord-like lymphatic glands. The disseminated subcutaneous type which is widely distributed over the surface of the body and the disseminated ulcerating form which is similar but is typified by multi-

ple ulcerating lesions are less commonly encountered. The epidermal type of sporotrichosis is less severe than the other forms. It may show nodular lesions, plaques, and areas of folliculitis. The systemic type is, as the name implies, a wide-spread infection which may involve the bones, joints, lungs, and liver. The disseminated variety is usually fatal if untreated. An allergic form of sporotrichosis may resemble various other dermatological entities.

The portal of entry is usually through the skin by means of a prick, bite, or scratch. Sporotrichum has been found in thorns, moss, hay, and other vegetation, and on horses, dogs, cats, rabbits, and rats. The disease may remain localized or may be spread by the lymphatic glands or by the blood stream. Pathological examination shows the local tissue reaction to be non-specific.

FIG. 1-C

High-power view of cigar-shaped spore on direct smear from aspirations of the knee.

Histopathologically, the sporotrichum fungus consists of three zones (Figs. 3-A, 3-B, and 3-C). The central zone consists of polymorphonuclear leukocytes and macrophages. The zone surrounding this center is tubercular in appearance with epithelioid cells, giant cells, and tuberculoid follicles. The external zone consists of lymphocytes and connective-tissue cells and is basophilic with comparatively intense vascularity, frequently exhibiting an almost syphilitic-type sclerosis.

Diagnosis is determined by culture. There is usually a history of an abrasion or scratch, and the physical findings vary with the clinical types. In the disseminated form, there may

be involvement without severe clinical symptoms. There may be low-grade fever. Roentgenograms of bone involvement may closely resemble osteoporosis or tuberculous bone lesion. The tibia is the bone most frequently affected. Pathological fracture may occur.

In serological tests on mice, sporotrichum may be positive in 1:25 to 1:00 dilution. The intradermal skin test is usually positive, and the organism may be found in aspirated material from abscesses, or in smears and cultures from draining sinuses. Blood cultures have also yielded the organism.

The condition may be mistakenly diagnosed as tuberculosis, syphilis, villonodular synovitis, and other mycotic infections. Villondular synovitis was the tentative diagnosis

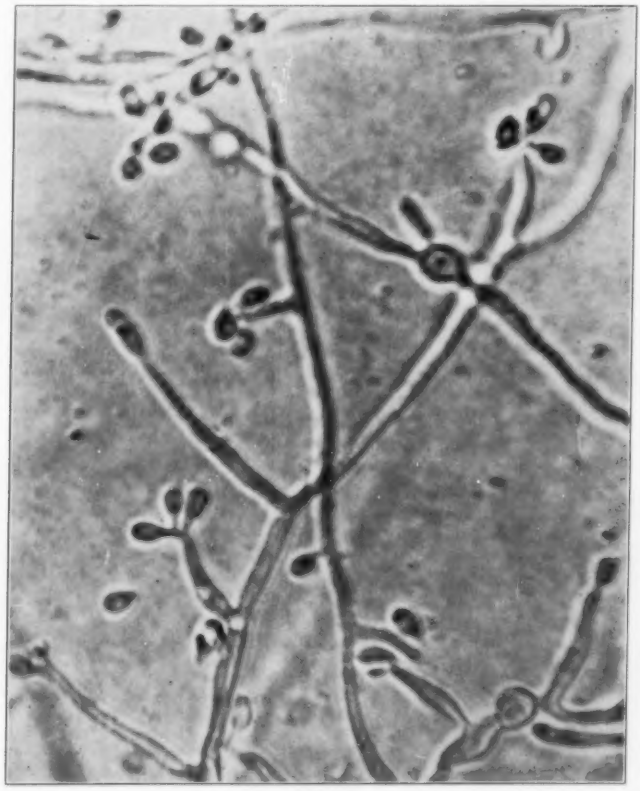

FIG. 2

The branching mycelia showing pear-shaped conidia at irregular intervals along the mycelium, appearing as terminal triad or tetrad clusters.

in the case reported here, and it was also the tentative diagnosis in a case of coccidioidal synovitis of the knee reported in recent literature[25].

The recommended treatment has been massive doses of iodides over prolonged periods of time. However, in the case reported here, 100 drops of saturated solution of potassium iodide were given three times a day for periods extending over weeks without significant results. Stilbamidine was used alone and in conjunction with potassium iodide, and was given both systemically and locally without reducing the infection. Its use was discontinued because of the toxic effects.

J. Z., a white farmer, thirty years old, entered the Veterans Hospital, Lincoln, Nebraska, on March 3,

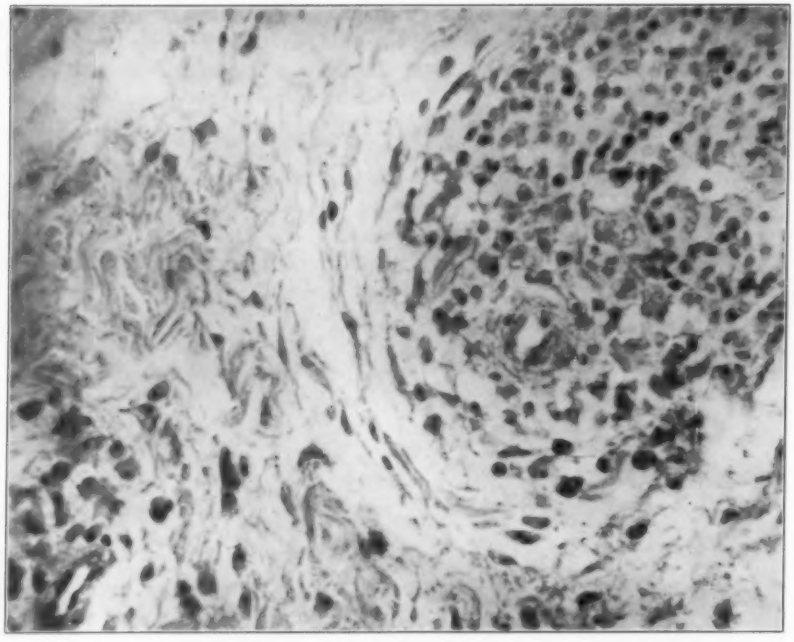

FIG. 3-B

High-power view of epitheloid follicle. Some of these show evidence of caseation in the mid-portion.

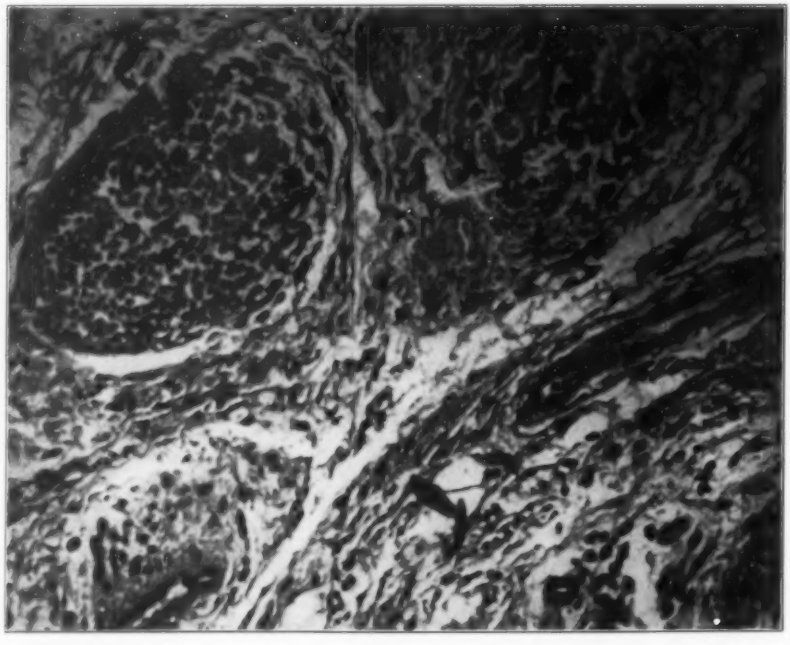

FIG. 3-A

Zone of tuberculoid follicles with epitheloid cells surrounding the central zone of polymorphonuclear leukocytes and macrophages.

1952, with a history of pain in the right knee of six months' duration. The pain was first noted on getting out of bed one morning.

Four months later the knee became swollen, and the dull aching pain changed to a severe throbbing one. Prior to the patient's admission to the Hospital, fifty cubic centimeters of serosanguineous fluid were aspirated from the knee and a walking cylinder applied. This gave him some relief, but the aching discomfort immediately returned when the plaster support was removed.

Physical examination upon admission was negative except for the swelling and a definite area of induration about the right knee, with evidence of synovial hypertrophy and thickening, particularly in the suprapatellar region. There was no history of trauma and no history of fever. There was no evidence of ulceration or of skin involvement. There was no local heat or redness and the major ligaments were stable. Motion was normal with the exception of slightly limited flexion. There was some atrophy of the quadriceps, but there were no skin changes or scars and no evidence of lymphangitis or adenitis.

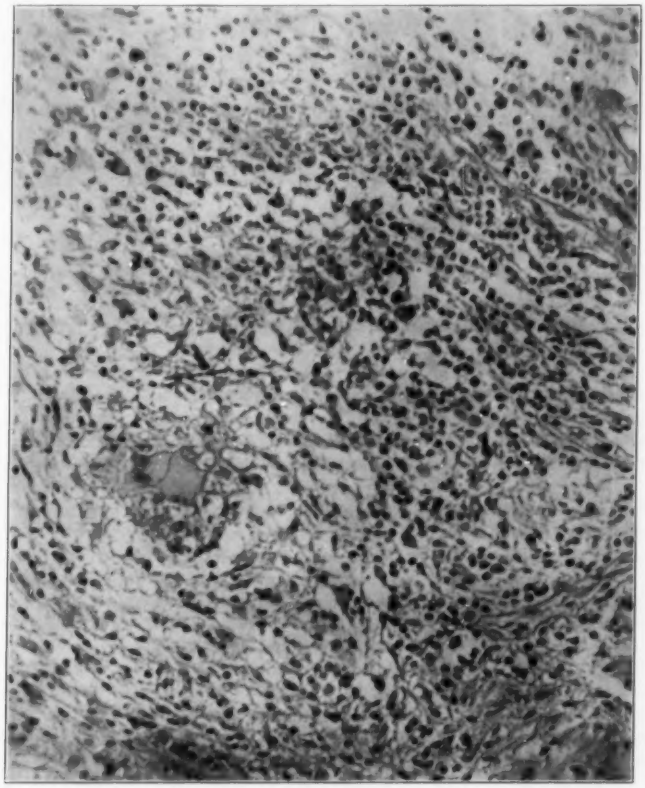

FIG. 3-C

Giant cells within the medial zone.

At the time of admission, the patient's urinalysis, routine blood count, and differential blood count were within normal limits. Blood tests were within normal limits. Brucella agglutinations were negative. Typhoid titers were also negative. The sedimentation rate was forty millimeters per hour (Westergren).

The patient's lower extremity was placed in traction and aspiration of the knee was done. The resulting fluid was reddish-brown and viscid. This was routinely cultured for pyogenic organisms and tuberculosis; both cultures were reported negative. A direct smear culture for pathogens was also negative. A pneumoarthrogram was made of the knee (Fig. 4) which showed definite irregularity and hypertrophy of the suprapatellar region and extension of synovial tissue about the medial aspect of the proximal portion of the tibia. First and second intradermal purified protein derivative tuberculin tests were both negative. In the absence of positive culture and in the presence of synovial hypertrophy with serosanguineous effusion, a tentative

FIG. 4

FIG. 5

Fig. 4: Pneumoarthrogram showing the thickening and irregularity of synovial tissue in the suprapatellar area and the medial aspect of the proximal tibia.

Fig. 5: The knee following anterior synovectomy. The incision healed *per primam* without sinus formation.

diagnosis of villonodular synovitis of the knee was made, and three weeks after admission an exploratory arthrotomy was done.

On exposure of the knee joint through a median parapatellar incision, the synovial membrane was found to be thickened and dull gray, with multiple loose tabs in the joint. In the suprapatellar area there were sharp overlapping ridges. The joint contained a serosanguineous fluid, and both menisci appeared to be degenerated, softened, and loosened from their attachments. There was some pannus covering the intercondylar notch over the cruciate ligaments. All synovial tissue observed through the anterior approach was removed and both menisci were resected. It was evident on gross examination that the lesion was not pigmented villonodular synovitis. The incision was closed and a compression dressing was applied; the wound healed without ulceration or sinus formation (Fig. 5).

The synovial membrane was reported by the pathologist to be thickened, with lobulated areas protruding from the surface, giving it an irregular and hemorrhagic appearance. The cut surface was dull red-brown. Seen microscopically, sections appeared hyperplastic with granulation tissue on the surface. The surface was pale, with pink-staining mucoid material infiltrated with chronic inflammatory cells. There was moderate infiltration of leukocytes and plasma cells and a few granulomatous nodules were present; the mid-portion of these appeared to be undergoing caseation. Around the periphery was an epithelial infiltrate. An occasional giant cell was associated with these tuberculomatous areas, and no organisms were found. Sputa, gastric washings, and culture of urine were negative for tuberculosis, and scratch tests were done for cephalosporium and sporotrichum. All results were negative.

The fluctuant swelling about the knee and over the upper portion of the tibia persisted and the knee was aspirated again. Special mold and fungus cultures were made of the aspirated fluid on Sabouraud's media, and from these a culture growth was obtained which was identified as *Sporotrichum schenckii*. This was confirmed by Dr. Norman F. Conant of Duke University. An agglutination test with the patient's serum was positive at a titer of 1:640. Cigar-shaped bodies were also found on direct smear of aspirated fluid from the extension of synovial tissue about the medial aspect of the proximal end of the tibia, and numerous blood cultures were made; one of these was reported to be positive for sporotrichum. There was no sensitivity of the organism to any of the antibiotics or sulfonamides.

The extremity was kept at rest, and the patient was given gradually increased doses of a saturated solution of potassium iodide until the level of 100 drops three times a day was reached. This was a dosage level of approximately 19.5 grams of potassium iodide a day. Plaster immobilization was intermittent; it was hoped that some function of the joint could be preserved.

Serum protein-bound iodine reached a level of 6,000 gamma (seven to twelve gamma is normal). After six weeks of this therapy an iodide reaction developed in the patient resulting in a skin eruption. The knee remained swollen and the aspirations continued positive on culture.

FIG. 6

FIG. 7

Fig. 6: Roentgenogram of the tibia and fibula showing evidence of a round cystic area in the metaphysis of the tibia and irregular areas of bone resorption in the lateral proximal aspect of the fibula. Biopsy specimens taken from both bones failed to show presence of granulomatous material.

Fig. 7: The extremity after arthrodesis of the knee. The small incision scarcely seen in the lateral aspect of the knee is the site of the excision of a granulomatous mass which developed following primary synovectomy, while the patient was on medical therapy. The scar on the medial aspect is the site of pin fixation.

The iodide was discontinued and a daily dosage of 150 milligrams of stilbamidine per 1,000 cubic centimeters of glucose was given the patient intravenously for a period of thirty days, and thereafter, every other day for ten days. The condition, however, did not respond to treatment and cultures made from the knee aspirations continued to be positive. However, during the course of this treatment the fluctuant extension of synovial tissue about the tibia disappeared. Ten days after stilbamidine therapy was begun, the patient began to complain of burning and watering eyes and hypersensitivity of the skin, particularly over the trigeminal area of the face, which gradually spread down over the trunk and upper extremities. The patient's nose and ears felt as if they had been frostbitten.

Ten to fifteen milligrams of stilbamidine were injected every two days into the pockets of the knee, and at weekly intervals, one cubic centimeter of hydrocortone was added to the stilbamidine to increase the diffusion of the drug. These injections were continued for a period of six weeks, but periodic aspirations from the patient's knee continued to demonstrate positive cultures. There was very little discomfort of the knee and the injections successfully controlled the effusion. However, the paraesthesia progressed to the patient's hips and thighs, remaining most marked, however, on his face and the upper portion of the trunk. There was definite discomfort when deep pressure or pinching was applied to any of these areas, and the patient was unable to use a regular razor for shaving. A facial twitch developed and he was bothered with blinking and tearful eyes; it became necessary for him to wear dark glasses when in the sunlight. Although there was a decrease in light-touch sensibility, there was no reduction of pain and temperature, and after the onset of symptoms in the face the condition appeared to have no specific location but was diffuse over the trunk, upper extremities, and head. The patient experienced a temporary exacerbation of the discomfort for a few days following stilbamidine injection.

Frequent laboratory checks of renal and liver function were done, but these remained normal, as did the peripheral blood studies. The sedimentation rate remained consistently elevated, measuring from 36 to 45 millimeters (Westergren) per hour for seven months. Thereafter, it dropped to within normal limits and remained there.

Following the patient's early surgery and during medical therapy, adhesions developed in the suprapatellar area with pockets of effusion in the joint. On the lateral aspect near the superior pole of the patella, a large bursa-like granuloma developed which increased steadily in size until, one year after his admission to the Hospital, this mass was excised. It was found to communicate with the knee joint, and the articular surface of the knee revealed considerable erosion and degenerative changes. The excised specimen did not resemble the thickened tissue seen in the synovial membrane at the time of his first arthrotomy. It was of a

fibrous, granulomatous nature with necrosis, and the mass measured six to seven centimeters at its greatest diameter. It was filled with a serosanguineous, cloudy fluid. The lining of the mass was found to be full of caseous material. The articular surface of the femur was eroded and yellow in appearance, and a dense connective tissue film covered the entire articular surface. The patient was given an injection of fifty milligrams of stilbamidine prior to closure of the wound and a plaster cast was applied. The incision healed by primary intention without formation of a sinus. The fluid contained in the mass was cultured and organisms were found. Microscopic examination revealed a thickened, fibrotic membrane containing areas of multiple abscesses. These did not show evidence of granulomatous lesions.

The early roentgenograms of the knee showed some diffuse osteoporosis of the femoral condyles and of the proximal portion of the tibia and the patella without evidence of osteoblastic activity. There appeared to be a cystic area just distal to the tibial spine in the metaphysis, and some punched-out areas of osteoporosis in the fibula. It was suspected that these areas of rarefaction might be foci of infection and, therefore, before considering any definite surgical treatment, it seemed advisable to perform a biopsy of the bone structure from these areas in order to prove the presence or absence of granulomatous involvement of the bone (Fig. 6). This was done, and no evidence of granulomatous material was found.

Because of the ineffectiveness of the drug therapy and its toxic effect on the patient, and because of the danger of systemic involvement from infection of this type, in addition to the fact that the man was under severe emotional strain, two drastic procedures were considered—either amputation of the extremity, or excision and arthrodesis of the knee following the old principles of treatment of granulomata. Arthrodesis was decided upon after the pathologist's report. Had granulomatous extension been found in the bone marrow, arthrodesis would not have been feasible.

A compression type of arthrodesis of the right knee was performed. A complete débridement of the knee was carried out with resection of the joint and as much of the involved soft tissue as possible. The patient was again given stilbamidine intravenously, 150 milligrams daily for a week beginning the day before surgery. However, the patient suffered an exacerbation of his former sensory complaint and as the results of bromosulphalein test indicated early liver damage, the drug was permanently discontinued. Potassium iodide therapy was substituted and continued for a period of three months following surgery. The wound healed *per primam* approximately one week after discontinuance of the stilbamidine therapy. The paraesthesia about the patient's head and trunk began to subside.

Pathological examination of the tissue removed when arthrodesis was performed showed no gross changes in the bone structure, but marked cartilaginous degeneration was observed and the synovial membrane showed chronic reaction of the granulation tissue, non-specific in type, but proved by laboratory tests to be caused by *Sporotrichum schenckii*. Fibrous union developed in the joint operated upon and a second arthrodesis of the right knee was done, a bone graft taken from the right ilium being used. At the site of the pseudarthrosis a considerable amount of fibrous tissue was found in the knee with adjacent bone of poor quality. The fibrous tissue was excised, the bone graft was channeled across the joint line, and a cast was applied.

Specimen of the tissue removed during the second arthrodesis showed dense fibrous connective tissue with new bone being formed, and, in some areas, well developed bone trabeculation with active osteoblastic activity. Very little calcium was deposited, but there was no evidence of granulomatous involvement and cultures were negative.

There was no recurrence of symptoms or local tissue change after the first arthrodesis of the joint and excision of the involved area.

Following the second operative procedure, complete osseous consolidation of the knee was obtained and at the time of the patient's discharge on November 17, 1954, there was no evidence of local recurrence (Fig. 7).

The patient's general physical condition was excellent. Laboratory tests showed that liver, kidney, and peripheral blood were normal. The skin had cleared of all iodide reaction and there was considerable subsidence of the paraesthesia over the trunk and face, although he continued to use an electric razor and to wear dark glasses when in the bright sunlight. The facial twitching had ceased. He still complained of burning sensation in the eyes, particularly when in direct sunlight, and of numbness of the end of the nose and of the ears, which, he said, felt like frostbite. Also he described a sensation at the tip of his tongue which felt, he said, "as though it had been burned in hot coffee". There was no evidence of neurological change, and there was good muscle coordination and function.

CONCLUSION

Chronic synovitis of sporotrichal origin involving an isolated joint is a rare condition according to medical literature. In the case reported, the patient had no skin manifestations and the condition was not part of a widely distributed systemic type of infection.

The primary focus of infection was not affected by medical treatment and the drug that was used, stilbamidine, was found not only to lack therapeutic action but to have a toxic effect on the patient. The value of the old principle of absolute rest combined with

arthrodesis of the involved joint and excision of localized chronic granulomata was demonstrated in this case.

NOTE: Grateful acknowledgment is made to Dr. John R. Gordon, Department of Medicine; Dr. J. H. Barthells, Consultant in Dermatology; Dr. Paul Kisner, Chief of Pathology; Mr. Benjamin Sahagian, Research Biochemist; Mr. Robert A. Patterson, Chief of Bacteriology Section; and Mr. Bert E. Newkirk, Jr., Hospital Photographer, for their assistance in the preparation of this report.

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Ewing's Sarcoma

A Case Report

BY MAURICE A. BERNSTEIN, M.D., BEVERLY HILLS, CALIFORNIA

This is the report of a case of Ewing's sarcoma, a rapidly growing malignant tumor of the fibula, in an eight-year-old boy who is alive and well twenty-eight years after the amputation of his leg. The report should be of interest since it is the only record in medical history, to my knowledge, of a patient who has undergone surgery for this condition and has survived for many years. The fortunate circumstance is, that despite the rapid growth of the tumor as shown in the accompanying roentgenograms, metastasis had not taken place. Since the operation in 1928, the roentgenograms and the microscopic slides have

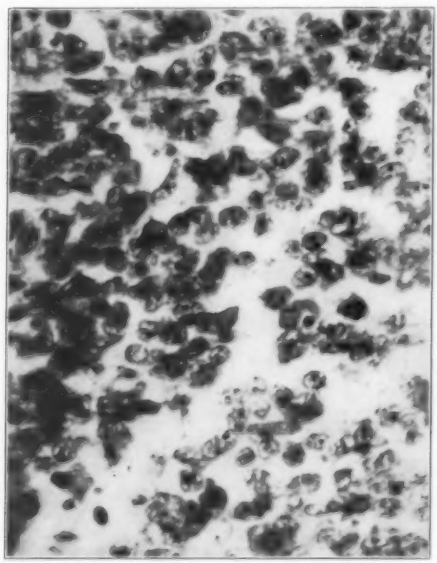

FIG. 1

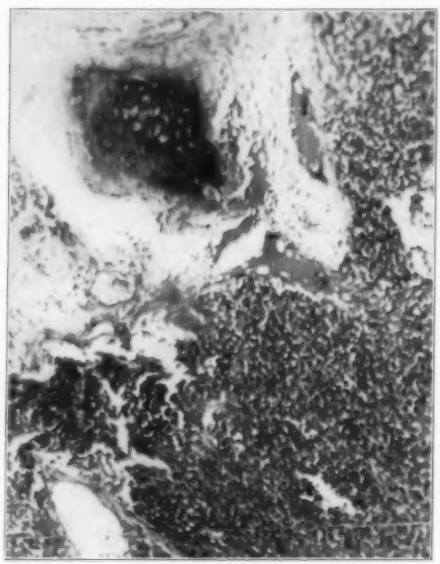

FIG. 2

Fig. 1: Photomicrograph of a Ewing tumor, showing the cytologic pattern, scant cytoplasm, and some mitotic figures.

Fig. 2: Photomicrograph showing the organoid structure of the tumor and dead bone fragments.

been seen by Ewing, Phemister, Bloodgood, Geschickter and other pathologists. They have all agreed that this was Ewing's sarcoma, thus confirming the original diagnosis.

Ewing's sarcoma has been the subject of considerable controversy, pathologically, and has been associated with reticulum-cell sarcoma, neuroblastoma, and metastatic carcinoma. Malignant tumors have poor prognosis and we are inclined to postpone a radical approach to bone tumors in fear of a possible wrong diagnosis, and, in consequence, the sacrifice of a limb. I believe that many times life could be prolonged if prompt diagnosis were made in all cases of malignant bone tumors and radical treatment immediately carried out. One can never be sure that metastasis has not occurred when discovery of the lesion is made. Roentgenograms of the chest are done routinely in all patients, of course, but even the negative result of these roentgenograms is not sufficient evidence that metastasis has not taken place. Sufficient biopsy material should be removed for adequate

microscopic study as assurance against mistaken diagnosis. Dr. John B. Murphy once said, "You do little damage when you remove enough bone for study, but you strike a mortal blow when you scrape material for the pathologist" (Figs. 1 and 2).

FIG. 3

FIG. 4

Fig. 3: Roentgenogram of the patient's fibula made October 8, 1928, showing diffuse involvement of the marrow and cortical bone, with no tendency to osteogenisis.

Fig. 4: Roentgenogram of the patient's fibula made two months later, on December 12, 1928, showing rapid destruction of the cortical bone and the greatly increased tumor.

An eight-year-old boy was struck on his left leg while he was playing on September 15, 1928. He continued at play, but that night he experienced so much pain in the leg that his sleep was disturbed. He went to school the following day, although he limped a good deal. A few days later, a small bleb formed on the outer middle portion of the leg at the place where he was struck. This broke open and a small amount of serous fluid escaped. On October 8, 1928, the boy was taken to a doctor who examined him and made roentgenograms of his leg (Fig. 3). A diagnosis of osteomyelitis of the fibula was made, and he was taken to the hospital where the fibula was curetted. The curetted material was sent to the laboratory and the diagnosis of osteomyelitis was confirmed by the pathologist. The boy's leg continued to swell, although there was little pain and he was able to walk without undue discomfort. I was called into the case in consultation and saw the boy first on December 29, 1928, about three months after the onset of the condition. On examination, the leg was found to have increased in circumference and there was a slight amount of serous exudate from a sinus. The affected leg was warmer than the other. There was no fluctuation but marked crepitation could be detected. There was a rise in the boy's temperature in the afternoon, and the leukocyte count was slightly elevated. Roentgenograms, made at this time, showed a rapidly developing tumor involving almost the entire length of the fibula (Fig. 4). The mass extended from one and one-half inches above the distal epiphysis to the proximal epiphyseal line. The fibula appeared club-like; the lamellae were spread apart by a ballooning honeycomb-like destructive process which left only a shell of bone. The tumor was trabeculated, and these trabeculae were walled off and appeared to be filled with a substance similar to the contents of a cyst. The periosteum showed fine parallel layers resembling the layers of an onion which is characteristic of Ewing's tumor. In some places, fine needle-like transverse processes appeared to radiate from the periphery. The medullary canal below the tumor was decalcified. The greatest change was seen in the upper two-thirds of the fibula. Here the fibula had become a large confluent cyst, the center of which was divided by septi into numerous lobules. The cancellous bone appeared to be consumed by a rapidly spreading, liquifying process. At some points, breaks in the continuity of the periosteum were seen, and the tumor had perforated into the soft parts of the leg.

The boy was admitted to Michael Reese Hospital, Chicago. Roentgenograms of the chest made at that time showed no metastasis. A biopsy specimen was taken and a microscopic examination was made while the boy was on the operating table. The pathologist's report diagnosed the condition as a malignant neoplasm. The boy's leg was at once amputated above the knee joint. The patient made an uneventful recovery.

In 1928, nearly all malignant bone tumors were diagnosed as round-cell sarcoma. This was the diagnosis of the case reported, but when the boy lived beyond the three-month period expected and appeared to be recovering, the microscopic slides were studied again. A new diagnosis was returned — that of organoid tumor, the endothelial myeloma of Ewing. Since the operation in 1928, roentgenograms made periodically of the boy's chest have showed no signs of metastasis.

An Anti-Scissoring Device for Patients With Cerebral Palsy *

BY SAMUEL B. THOMPSON, M.D., LITTLE ROCK, ARKANSAS

The various forms of scissoring which occur in the walking of most patients with spastic cerebral palsy can usually be controlled satisfactorily with a pelvic-band brace constructed of light-weight metal and leather. There are, however, athetoid or dyskinetic patients with such extreme tension in the adductors and rotators of the hips that a brace made of metal heavy enough to control their severe bodily contortions would make the device too heavy for practical use. In an effort to solve this problem, Mr. R. T. Hickerson, a bracemaker of Little Rock, Arkansas, was asked to design a supplement to the light-weight brace in common use to control these forces. The device described in this report is the result of his three years' work and experimentation.

FIG. 1

Fig. 1: The parts of the anti-scissoring device: the C-shaped enclosed housing, the bearing bar fitted with cylindrical roller bearings, and the ball-bearing cap.

FIG. 2

Fig. 2: A pelvic-band brace with the anti-scissoring device in place.

The appliance consists of an enclosed C-shaped housing, which is concave on its closed side and convex on its open side, and a T-shaped bearing portion which fits within this housing. The curve of the housing accommodates itself to the arc of motion of the thighs in walking. The housing is fastened permanently to the inside bar of the limb brace on one side and the T-shaped bearing piece to the inside bar of the brace on the opposite limb. The pelvic band is an essential adjunct to the use of this device. The T-shaped bearing piece has a roller bearing on each end of the cross of the T, and a single five-eighths of an inch ball bearing at the very top of the T.

When the legs attempt to scissor, the ball bearing comes in contact with the top portion of the housing and the cylinder bearings come into contact with one side of the housing, effectively preventing the two limb braces from touching each other. There is no binding of the device on rotation because the cylinder bearings at each end of the crossbar of the "T" contact the side walls of the housing whatever the direction of rota-

* Exhibited at the Annual Meeting of the American Academy for Cerebral Palsy, Williamsburg, Virginia, November 4–6, 1954.

tion. Abduction of the portion of the brace carrying the bearing piece, with simultaneous adduction of the portion of the brace carrying the housing, can be controlled by the addition of a cap containing a ball bearing, to roll on the top of the housing when fastened to the inside bar of the brace carrying the bearing piece. With these four bearings, rolling friction can be obtained regardless of the direction of the forces applied by the two thighs.

In the Arkansas cerebral palsy program, this device has been in use for five years and has been applied on eighty patients. It has proved effective in controlling the disturbances of gait produced by excessive adduction, abduction, internal rotation, external rotation, and various combinations of these forces at the hip joint.

Shoe Pad for Treatment of Calcaneal Spur *

BY G. W. N. EGGERS, M.D., GALVESTON, TEXAS

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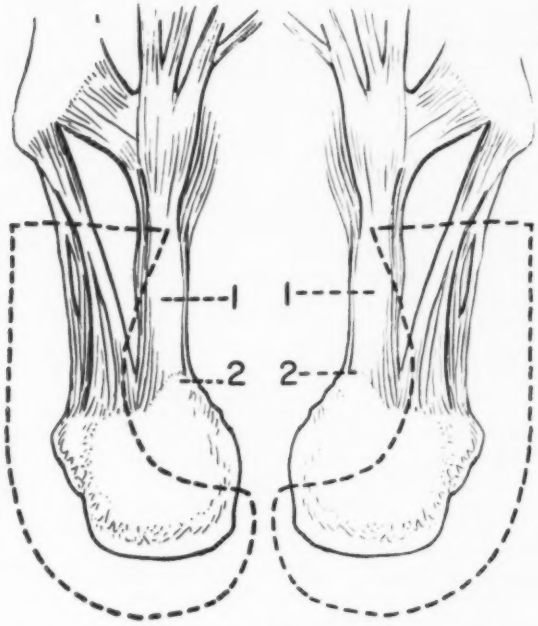
The painful heel which, roentgenographically, shows a calcaneal spur is frequently considered a surgical problem. The condition is caused by plantar fasciitis and occasionally



R FIG. 1 L

FIG. 2

Fig. 1: Drawing (plantar view) showing relation of pad to heel. *1*, plantar fascia; *2*, medial tubercle where spur forms.

Fig. 2: Shoe showing placement of pad.

* Based on a Gadget and New Idea Exhibit presented at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28 to February 2, 1956.

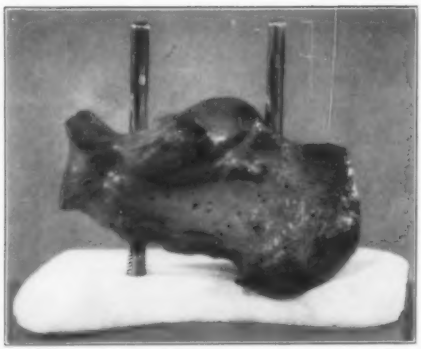


FIG. 3-A

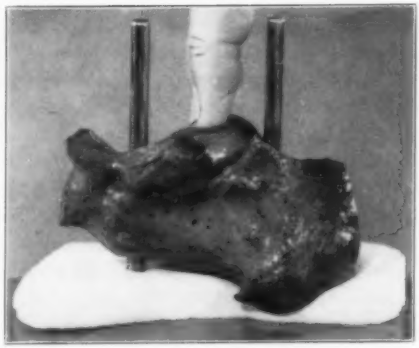


FIG. 3-B

Fig. 3-A: Position when pressure is not on the heel.

Fig. 3-B: Pressure on the heel showing that the pad prevents the spur area from touching the shoe sole.

by a bursitis between the fascia and the calcaneal spur. To relieve pressure on the painful area, we have for years recommended to our patients a comma-shaped shoe pad which has been found very satisfactory. The use of this device has for many years eliminated the need for surgery in these patients. Slight adjustments may be necessary in order to relieve the pressure on the spur.

The mechanical principle of the pad is to relieve pressure and to lessen strain on the medial aspect of the calcaneus where the medial plantar fascia is inserted into the area of the spur. The shape and construction of the pad does this. It must be of sufficient height to prevent pressure on the spur, and although the pad may be made of any material, we have found that sponge rubber, one-half inch thick, is the most satisfactory.

DISCUSSION

IMMOBILIZING EFFICIENCY OF BACK BRACES

(Continued from page 139)

take the time to make a copy of the brace and try it out, certainly deserves to be complimented. I should like to comment on one point that he made in particular. He postulated that any brace, to immobilize this area of the back effectively, must grip both the pelvis and the thorax. If this were possible, I would agree. However, it was our finding that no brace, regardless of the type of pelvic attachment used, actually did grip the pelvis effectively. This was the reason that we abandoned all braces designed to grip the pelvis and resorted to the present brace which gives a low point of fixation and localizes pressure as near the point where immobilization is desired as possible.

Proceedings

AMERICAN MEDICAL ASSOCIATION
SECTION ON ORTHOPAEDIC SURGERY

As Reported by Frederick R. Thompson, M.D., *Secretary*, New York, N. Y.

The Annual Meeting of the American Medical Association was held in Chicago, Illinois, June 11 to 15, 1956. Summaries of the papers presented at the sessions of the Section on Orthopaedic Surgery follow:

Metatarsus Primus Varus and Hallux Valgus. Dr. Donald C. Durman [1] had made a study of 356 normal feet in order to demonstrate that hallux valgus seldom exists in the absence of a varus deformity of the first metatarsal. In children as well as in adults the degree of hallux valgus is usually proportionate to the degree of metatarsus primus varus. By determining the direction of the long axes of the first and second metatarsals, the author had found that these metatarsals converge at an angle of less than 10 degrees in the normal foot and at an angle of more than 10 degrees in the foot with hallux valgus. He felt that to correct the hallux valgus deformity without correcting the varus deformity of the first metatarsal is unwise, and for twenty years he had corrected both deformities. In the early operations he had done a wedge osteotomy of the neck of the first metatarsal (Peabody method) combined with a wedge osteotomy of the base of the first metatarsal. In the later cases, however, after correcting the hallux valgus by means of the wedge osteotomy of the metatarsal neck, he had arthrodesed the first metatarsal-cuneiform joint, placing a bone graft on the medial side of the joint in order to maintain the position of the bones. Splints had then been applied and the patient had been allowed to walk on the outer border of his foot as soon as he desired. Full weight-bearing had been allowed after three weeks, the patient wearing a cut-out shoe with longitudinal and metatarsal arch supports. The complications which had developed following this operation had been minimal, the most frequent complication being persistent swelling of the foot. One hundred and fifty-nine feet in eighty-three patients had been operated upon, and all but five patients had been available for follow-up examination. Only one patient had been dissatisfied and had been re-operated upon. No recurrence of the varus deformity of the first metatarsal following fusion of the joint had been noted. There had been three instances of pseudarthrosis at the first metatarsal-cuneiform joint.

In the discussion Dr. Joseph L. Fleming [2] and Dr. Walter R. Fischer [3] pointed out that this operation has a place in the treatment of hallux valgus deformities, but that the simpler Keller operation is more applicable for older people since the period of postoperative disability following this operation is much shorter.

Compression Neuropathy of the Median Nerve in the Carpal Tunnel. Dr. George S. Phalen [4] and Dr. James I. Kendrick [5] reported seventy-one cases of compression neuropathy of the median nerve. In forty-nine of these cases operation had been required. The presenting complaints in this series had been pain, numbness, and tingling in the median-nerve distribution distal to the wrist, and the diagnostic signs had been the presence of Tinel's sign at the wrist, increase of symptoms following flexion of the wrist, and atrophy of the thenar muscles. Thirty-eight patients had had atrophy, a symptom which is best determined by observing the thenar eminence from the lateral side. Many had showed pin-prick changes distal to the wrist along the thumb and index finger. The majority of the patients were women in middle life; there were fifty-four women as compared with seventeen men.

Any condition that alters the contour of the carpal tunnel or increases the volume of its contents may produce compression neuropathy of the median nerve. In some cases the condition has been a ganglion, a hemangioma, or chronic rheumatism, but the condition that has most commonly caused this nerve compression is chronic non-specific tenosynovitis. Median-nerve compression is seldom an occupational hazard.

In the authors' series some patients had responded favorably to local injections of hydrocortone. In most cases the operative treatment had consisted in simple section of the transverse carpal ligament (without excision), but in some cases partial synovectomy had also been necessary because of marked thickening of the synovial membrane. In 50 per cent of the patients swelling of the nerve had been found proximal to the area of compression, while in 60 per cent the nerve had been found to be flattened as it passed over the wrist. In 70 per cent there had been some thickening of the synovial membrane.

Relief from the prominent burning pain had been obtained in all patients, but relief from numbness

[1] 408 South Jefferson Avenue, Saginaw, Michigan.
[2] 2799 West Grand Boulevard, Detroit 2, Michigan.
[3] 111 North Wabash Avenue, Chicago 2, Illinois.
[4] 2020 East 93rd Street, Cleveland 6, Ohio.
[5] 2020 East 93rd Street, Cleveland 6, Ohio.

and atrophy had not always been obtained. If the atrophy persisted for more than a year, it was considered to be probably permanent.

In the discussion, DR. ROBERT E. CARROLL [6] stated that the term *rheumatic* is incorrect, for in compression neuropathy of the median nerve there are no elevations of the sedimentation rate and there is no positive sheep-cell agglutination. He believed that the condition is a type of chronic and non-specific tenosynovitis which is similar to the stenozing type of tenosynovitis. He stated that if degeneration of the nerve fibers is demonstrated by a chronaxy study, the patient should be operated upon immediately. He cautioned against the use of a transverse incision, stating that this incision provides only minimal exposure.

DR. MICHAEL L. MASON [7] stated that the condition is frequently associated with the climacteric and that relief may be obtained by the administration of estrogen. In his series he had found that the condition sometimes occurs many years following a Colles' fracture. He believed that it might be an occupational hazard and presented as an example a case in which it had been caused by the patient using the heel of his hand to pound boards into position. He had noted that if sensory responses to pin pricks had been absent for some time, they had not always returned following treatment.

The Doctor and the Automobile Accident. DR. MURRAY E. GIBBENS [8] and DR. WILLIAM B. SMITH [9] had made a study of the files and photographs of the Colorado State Highway Patrol Accident Bureau. From this study they had determined that no make of automobile ensures the safety of the passengers in the event of collision or rolling over of the car. Their study had also revealed, however, that often, although the engine compartment and fenders were badly damaged and the doors open and bent, the actual passenger compartment itself was intact and not badly damaged. If the passengers riding in the cars that had been damaged in this way had been strapped to their seats and so had not been thrown out through the open doors, many would have been saved.

There are 2,000,000 automobile injuries a year, resulting in 38,000 deaths (a death rate of 100 per day or four per hour and an injury rate of 200 per hour). The use of safety features would greatly cut down injuries and fatalities. One excellent safety feature is to use a shoulder strap in addition to the waist belt, thus holding the driver or rider securely back against the seat. This support should certainly be made available to the passenger riding in the so-called "death seat" on the right front side of the car. The belts should be fastened to the frame or the floor of the car, not to the seat itself. There should be safety latches on the doors, or else a nylon belt should be extended (behind the front seat) from door to door to hold the doors shut. Hydraulic bumpers and left-hand rear-view mirrors should be mandatory, and there should be adequate windows in the back of the car. Electric stop signals should also be mandatory.

Cineradiography of the Normal Cervical Spine. DR. J. WILLIAM FIELDING [10] presented slides of roentgenograms and motion pictures, made with the aid of fluoroscopy, showing the normal cervical spine in motion. The motion pictures were arranged to demonstrate certain aspects of motion which would be difficult to visualize by slide techniques alone. The only motion permitted at the joint between the occiput and the first cervical vertebra is flexion and extension. The range of flexion is small, being 10 degrees or less, while that of extension is greater, being as high as 25 degrees. In the joint between the first and second cervical vertebrae, the range of motion is extensive. Rotation is the main component of this motion, but there is also a substantial degree of flexion and extension. A motion at this joint never before appreciated is vertical approximation of the segments during rotation. In the first part of the rotatory movement, the skull and first cervical vertebra move as a unit on the immobile second cervical vertebra below, the pivot of this rotation being the odontoid process. The ring of the first cervical segment thus swings quite far laterally across the foramen of the second cervical vertebra. This decreases the opening of the spinal canal between the two segments and causes angulation of the spinal column. Fully 90 per cent of rotation of the neck (which may be as much as 90 degrees) occurs at the interval between the first and second cervical vertebrae before the spine of the second vertebra begins to rotate on the vertebra below. From that point onward the remaining rotation occurs in the lower segments in decreasing amounts, above downward. Lateral tilt of the neck produces extensive rotation of the second cervical vertebra. Flexion and extension occur between the first and second segments in addition to rotation. There is usually about 10 degrees of extension but only 5 degrees of flexion. This flexion-extension movement is possible because of the shape of the facets, those of the second cervical vertebra being convex, while the lower facet of the first vertebra is not absolutely concave but is more or less flat. The flat facet above rocks backward and forward on the convex facets below. This movement does not become too exaggerated unless the transverse ligament which holds the odontoid process in place is lax.

The author demonstrated that during flexion of the lower cervical spine there is a forward displacement

[6] 180 Fort Washington Avenue, New York 32, N. Y.
[7] 154 East Erie Street, Chicago 11, Illinois.
[8] Veterans Administration Hospital, Denver, Colorado.
[9] Denver, Colorado.
[10] 742 Park Avenue, New York 21, N. Y.

of each vertebra over the one immediately below. This forward movement produces a narrowing of the disc space anteriorly and a widening posteriorly, as a result of which the lateral disc outline, as seen in the roentgenograms, changes from a rectangle to a trapezoid. In extension this situation is reversed. During flexion the facets are seen to shift their full length across each other so that in extreme flexion the posterior margin of the superior facet is opposite to or beyond the anterior margin of the lower facet. The margins of these facets could easily interlock if it were not for the fact that, during extreme flexion, they are vertically separated from each other as a result of a deformation of the disc accompanying the gliding action.

The discussors, Dr. Bedford F. Boylston [11] and Dr. Fay H. Squire [12], complimented the author on his cineroentgenography and on the importance of his findings. They felt that his findings would explain some of the whiplash injuries seen following trauma.

Intramedullary Fixation of Pathological Fractures. Dr. Einar W. Johnson, Jr.[13] stated that pathological fracture of a long bone due to metastatic disease may well be treated by intramedullary nailing. This treatment may reduce complications and prolong the life of the individual. When metastatic disease is noted in a bone prior to fracture, fracture can often be prevented by intramedullary nailing. Theoretically the introduction of the intramedullary nail might spread the tumor by causing an increase of systolic pressure within the medullary cavity; it would seem, however, that this danger could be minimized by driving the nail down the shaft with a gentle force rather than with a great force. In Gaucher's disease of the femur, the bone is pitted and weak and preventive nailing is of importance. Nailing is also valuable in the treatment of metastatic hypernephroma, myeloma, and osteogenesis imperfecta. The presence of a nail is not a contraindication to the use of roentgen therapy, and, indeed, it may be beneficial, for many aspects of secondary irradiation increase the therapeutic dose of roentgen rays locally. This therapy, when used, is given in three planes at the site of the lesion.

In the discussion Dr. J. Otto Lottes [14] and Dr. William A. Larmon [15] reported that in some cases of metastatic carcinoma of the breast, intramedullary nailing had prevented fracture of the femur despite the fact that some portions of this bone were so badly eaten away by the metastatic disease, as shown by the roentgenograms, that it was amazing that the patient could walk. Dr. Larmon suggested that nailing might stimulate the tumor to grow faster locally but felt that this factor might be discounted if roentgen therapy was given at the site of the lesion.

Foraminotomy and Fusion Following Disc Surgery. Dr. Dana M. Street [16] stated that in their enthusiasm over the good results which may be obtained by disc surgery, many surgeons overlook a cause of sciatic pain which received considerable attention prior to 1934, namely, bone impingement on the nerve root. This oversight may account for the many negative findings which have been obtained at primary disc exploration in some authors' series. Excising the facets and stabilizing the spine by fusion following facetectomy was described by Putti in 1927[a], by Ghormley in 1931[b], and by Williams and Yglesias in 1933[c]. The author stated that, regardless of the need for fusion as a primary procedure, there is little doubt of its great salvage value as a secondary procedure. He presented the cases of twenty-five patients who had continued to complain of sciatica and back pain after previous disc surgery without fusion; in these cases he had performed foraminotomy and fusion at the same operation. His procedure had consisted in a total excision of the facets. In the cases in which the foraminotomy had been done on the same side as the fusion, the lamina had also been removed and most of the pedicle had been trimmed flush with the posterior surface of the vertebral body. If a lateral fusion was to be attempted between the transverse processes, a part of the pedicle had been retained for stability. In the patients with the more usual hemilateral sciatic condition, a fusion had been performed on the opposite side from the foraminotomy at the same operation. Eleven of the author's twenty-five patients had complete remission of pain. In some the fusion had failed to become solid, and although the sciatica had been relieved, the back pain had persisted. Some of these patients had been re-operated upon, and fusion had been obtained with resultant relief from pain. Fourteen patients had had complete recovery from the sciatica and eight had showed partial recovery. There had been five incidences of pseudarthrosis with no relief of back pain.

In their discussion Dr. H. Relton McCarroll [17] and Dr. Charles F. Ferciot [18] stated that primary disc surgery is not always necessary. They also stated that fusion is not necessary as a primary procedure, but that it is indicated as a secondary procedure. If the sciatica is the result of bone impingement, the removal of the superior portion of the facet is the most important part of the secondary operation. This removal should be done widely.

[11] 5215 South Main Street, Houston 2, Texas.
[12] 1753 West Congress Street, Chicago 12, Illinois.
[13] 102 2nd Avenue, S.W., Rochester, Minnesota.
[14] 16 Hampton Village Plaza, St. Louis 9, Missouri.
[15] 700 North Michigan Boulevard, Chicago 11, Illinois.
[16] Kennedy Veterans Administration Hospital, Memphis 15, Tennessee.
[17] 3720 Washington Boulevard, St. Louis 8, Missouri.
[18] 1000 South 13th Street, Lincoln 8, Nebraska.

DR. STREET, in his closing remarks, emphasized that the facetectomy should be complete, with enlargement of the normal foramen to include a part of the pedicle, if necessary. Following the primary operation, scar tissue may extend well beyond the facets, and this should be excised until the nerve roots are free. Dr. Street believed that since facetectomy leaves a definite instability of the spine, fusion should always be done at the same operation.

a. PUTTI, V.: New Conceptions in Pathogenesis of Sciatic Pain. Lancet, **2**: 53–60, 1927.
b. GHORMLEY, R. K.: The Operative Treatment of Painful Conditions of the Lower Part of the Back. Proc. Staff Meet. Mayo Clinic, **6**: 112–114, 1931.
c. WILLIAMS, P. C., and YGLESIAS, LUIS: Lumbosacral Facetectomy for Post-Fusion Persistent Sciatica. J. Bone and Joint Surg., **15**: 579–590, July 1933.

The Use of Hydrocortone in Traumatized Knees of Rabbits. DR. CHARLES J. FRANKEL [19], DR. DAVID K. WEBSTER [20], and DR. THOMAS M. HAMILTON [21] had made a study of the local effect of hydrocortone upon the injured knees of rabbits. A control group of seven animals had been wounded in the knee and had then been sacrificed, without administration of hydrocortone, after three, five, ten, or fourteen days. Sections of the synovial membrane from these animals had shown chronic inflammation with fibrosis and no real evidence of healing. Another control series of fifteen animals had been injected with hydrocortone but had not been injured. In this group the authors had found that the animals most frequently injected had granulomatous reaction with degenerative changes and deposition of crystals in the synovial membrane. A group of twenty-six animals had been injured by means of controlled blows and twisting of the knees, and the knees had then been injected with hydrocortone at varying intervals. In the animals injected only once, one to seven days following trauma, there had been rapid healing. In the two animals injected twice, on the second and fourth days after trauma, the fourteen-day autopsy studies had shown marked fibrosis with more rapid healing. In the six animals given three injections of hydrocortone at two-day intervals, an increased reaction had been found in the synovial membrane.

The authors concluded that the local use of hydrocortone is a valuable adjunct in the treatment of traumatic synovitis, but that its overuse may cause granulomatous changes and delayed healing.

The Clinical Judgment of Scoliosis. DR. JOSEPH C. RISSER [22] stated that in the treatment of scoliosis the first step is to determine whether the deformity is postural or structural. This is done in part by noting the asymmetry of the patient's back when he is bending forward and in part by noting the structural rotatory changes apparent in the roentgenograms.

Scoliosis becomes noticeable when the angulation reaches 25 to 30 degrees. Without treatment a structural curve will become worse with vertebral growth. Because of the segmental growth of the spine, this increase will occur largely in the periods of rapid growth, particularly at the ages of eleven to fourteen. Deficiency diseases may promote greater increases in the deformity. Determination of the growth of the spine can only be made by accurate measurement.

The initial examination should include measurements of the patient's vertical height in standing, sitting, and kneeling positions. In addition, roentgenograms should include anteroposterior views made with the patient standing. An initial lateral roentgenogram is necessary in order to determine the degree of demineralization of the bone. The presence of the iliac apophysis indicates completion of vertebral growth. A scoliotic deformity becomes static with completion of growth, and when this occurs, the only treatment indicated is to correct the deformity and to relieve any pain which may be present. After sufficient explanation has been given, the final decision to correct the deformity must be made by the patient.

The correction may be carried out by means of the turnbuckle cast which applies traction and lateral pressure. Recently the turnbuckle cast has been superseded by the localizer body cast which is equally effective but which is without the drawbacks of the turnbuckle cast. The patient is ambulatory immediately and is far more comfortable. Correction is maintained by surgical fusion. In this procedure the entire curve must be fused, including all the vertebrae which show angulation and apical rotation.

The average amount of correction which may be obtained is about 25 degrees, and the best results (proportionately) are found in the patients with the smaller curvatures. The ease of correction is usually in inverse proportion to the duration of the curve. Correction and fusion should be done when the structural deformities are first noted, especially if further vertebral growth is expected. The surgery may be accomplished through a posterior window in the localizer cast or the cast may be bivalved. Fusion of the facets gives the greatest number of solid results. The patient is ambulatory immediately after the operation, and the total period of postoperative immobilization is about eight to ten months.

Failure to maintain correction is the result of an inadequate fusion as regards length or of failure of the fusion to become solid in one or more areas. Pseudarthroses should be repaired as soon as they are recognized.

[19] University of Virginia Hospital, Charlottesville, Virginia.
[20] University of Virginia Hospital, Charlottesville, Virginia.
[21] 218 Market Street, Mannington, West Virginia.
[22] 2637 East Washington Street, Pasadena 8, California.

In the discussion DR. CHARLES N. PEASE [22] and DR. JOHN H. MOE [24] agreed that the localizer cast is easier to apply and to handle than the turnbuckle jacket of Risser (this cast has been connected with the author's name for the past twenty-five years). They believed, however, that early ambulation tends to increase the curve by fully 10 degrees over what it would be if the patient remained in bed. They praised the author for his primary work in this field and for his spreading the gospel that brace therapy in scoliosis is not good orthopaedic treatment of the disease. Dr. Moe preferred Cobb's method of measuring the spine curve to the Ferguson method. All agreed that early fusion of a structural curve should be done.

Tendon Transplantation in Rehabilitation. DR. WILLIAM T. GREEN [25] stated that since the original description of tendon transplantation by Nicoladoni in 1881[8], many contributions to the technique of the operation have been made by European and American orthopaedic surgeons. Nevertheless, some surgeons still view the benefits of this operation with pessimism. For this reason the author has analyzed the factors that influence the results of such surgery.

Tendon transplantation represents the only possible means of replacing active muscular action in patients with permanent paralysis. It is also indicated for patients with deforming muscle imbalance and instability. The choice of the muscle to be transplanted must be considered in relation to the total function of the part and of the extremity, for one would certainly not transplant the hamstrings of the knee without knowing the muscular status of the hip. A transplanted muscle must be strong enough to carry out its new function and its pull must be effectively transmitted. When a peronaeus longus is transplanted forward for foot-drop, it usually serves as an effective dorsiflexor of the foot; yet when it is transferred alone to the back of the calcaneus for a calcaneus deformity, it has only moderate effectiveness. The need for strength in a posterior transplant for calcaneal foot is so great that it is sometimes necessary to transplant three or four muscles in order to replace the gastrocnemius-soleus action. In the upper extremity less strength is necessary, the need usually being for a single muscle with well controlled action. It is not true that antagonistic muscles are undesirable for transplants. While muscles of similar function or corollary activity provide the best and simplest solution to the problem of adaptation, antagonistic muscles can also be effectively transplanted. For example, the hamstrings may be transplanted to the patella and the tibialis anterior may be transplanted to the back of the calcaneus for a calcaneus deformity.

An essential decision is whether the muscles to be transplanted are more important in their transplanted position than in their original position, and it must be remembered that there may be some loss of action and power in the transferring. Occasionally a muscle can be transferred so that it will carry out its essential original function as well as its new one; for example, when the tibialis anterior is shifted to the middle of the foot in order to correct an inversion deformity, the original function of dorsiflexion is maintained. Deforming factors arising from growth following transplantation may need to be cared for later. When the peronaeus longus is transplanted, the unopposed tibialis anterior may elevate the first metatarsal with resultant flexion of the great toe, producing a dorsal bunion. For this reason, some surgeons prefer to maintain the peronaeus longus insertion and instead attach the peronaeus brevis to the distal tendon of the peronaeus longus, thus keeping the first metatarsal from being pulled dorsally. Others prefer to transfer the distal insertion of the tibialis anterior a little proximally toward the ankle. Arthrodesis prior to transplantation is not always necessary, provided the foot was stable and balanced before severe deformity developed.

The ideal situation for transplantation is one in which the muscle causing the deformity may be used to correct an essential weakness.

The age at which transplantation should be performed in a child often depends on the child's ability to train the transplanted muscle. The child usually has this ability at approximately five years of age, although some do not have it until they are older. The time of the operation may also depend, however, on the need to control the deforming factor, for if a child has a paralysis of the gastrocnemius-soleus group as a result of poliomyelitis and if a rapidly progressing calcaneus deformity is developing, much can be gained by doing a posterior transplant before the deformity becomes severe.

A transplanted muscle should not be required to work against a contracture deformity. The contracture should be corrected first. The pull of the muscle must be in a straight line from its origin to its insertion. A common error in this regard is not freeing the muscle sufficiently near its origin at the time of operation. The insertion should not be moved too far distally, and the blood and nerve supply to the muscle must be well protected. In the upper extremity the distal end of the transplanted tendon can be attached to other tendons, but in the lower extremity it is best to anchor the transplanted tendon to bone. Passage of the tendons through good sliding structures with adequate space is important, and when possible, the author preferred the use of smooth-lined compartments or tendon sheaths or the placement of the tendon beneath the deep fascia. He did not care for subcutaneous placement of tendons, except in the upper extremity. Suture material may be either silk or wire, and when possible, pull-out techniques, such as advocated by Dr. Bunnell, are advised. The transplanted muscle must be inserted under sufficient tension so that when the

[23] 104 South Michigan Boulevard, Chicago 3, Illinois.
[24] 78 South 9th Street, Minneapolis 2, Minnesota.
[25] 300 Longwood Avenue, Boston 15, Massachusetts.

patient is relaxed, the muscle will hold the involved portion of the body in the position which, when the patient is active, will be obtained by near-maximum contracture of the muscle. For example, a wrist transplant to accomplish dorsiflexion should, after insertion, while the patient is still under anaesthesia, hold the involved part in dorsiflexion. Similarly, a gastrocnemius-soleus transplant for calcaneus deformity should hold the foot in 30 degrees of equinus. A qualification of this, however, is that when there is some weakness in dorsiflexor power, the transplant should probably hold the foot in about 15 degrees of equinus. When the peronaeus longus is transplanted forward in order to provide dorsiflexion of the foot, the plaster should hold the foot at about a right angle or a few degrees beyond.

Postoperative care is believed to be an important factor in achieving the best results. Continued support in the overcorrected position is the first important rule. Prevention of contractures by stretching the transplanted muscle during the subsequent weeks is the second important rule. Early active exercises of the transplanted muscles are begun by the fifth to the seventh postoperative day. The cast is usually bivalved and the surgeon directs the beginning of the active motion, which is very small in range. Later, supervision of the exercises is turned over to the physical therapist and still later to a member of the family, usually the mother. As soon as the patient gets the "feel" of the transplanted muscle and its action, it is no longer necessary to carry out exercises which involve the original action of the muscle before it was transplanted. The type of exercise used thereafter is a straight, guided-assistant maneuver. The exercises are performed twice a day in the beginning and gradually increased until they are done as often as possible. Once an adequate range of motion has been achieved, resistance exercises to gain power are performed; these are not usually instituted until at least three months after transplantation. The next step after the simple action and power have been developed is to incorporate the motion of the muscle into the functional pattern of the extremity. For instance, a peronaeus longus transplant may be trained to dorsiflex the foot beautifully; yet, when the individual is called upon to walk, he still walks with the original drop-foot gait. Development of an association between the motion of dorsiflexion and the function of the foot is a necessary part of the training.

Braces and bivalved plasters are important in maintaining the position of the transplants during the night until strength has been achieved.

In conclusion, it was believed that tendon transplantation is a versatile, effective operative procedure. If the transplant is well planned, if the technique is meticulously followed, and if the subsequent training of the transplant is effectively performed, the individual will be greatly benefited.

a. Nicoladoni, C.: Nachtrag zum Pes Calcaneus und zur Transplantation der Peronealsehnen. Arch. f. Klin. Chir., **27**: 660–666, 1881.

The Effect and Management of Induced Hypoadrenalism on Patients Requiring Orthopaedic Surgery. Dr. James A. Nicholas [26], Dr. Philip D. Wilson [27], and Dr. Charles J. Umberger [28] reported that hypoadrenalism is frequently encountered in patients who need to undergo surgery. This condition may be of the spontaneous type, such as in Addison's disease, or it may be the result of the generalized use of steroid hormones in the treatment of arthritis and other diseases. In the past the diagnosis of hypoadrenal function before surgery has usually required intensive laboratory study and has involved more time and facilities than many patients can afford. The authors reported that they had found the following method to be a good test of hypoadrenalism. The salt excretion in the urine is measured during a twenty-four-hour period (the usual amount is 100 milliequivalents of salt a day). Following this measurement, an infusion of fifty milligrams of ACTH combined with 500 cubic centimeters of glucose and water is given over a four-hour period. The urine is then tested for salt during the next twenty-four hours. If the amount of salt excreted in the urine during this period is decreased by about 50 to 75 per cent, the patient's condition is normal. Failure to conserve the salt after the ACTH infusion should alert one to the possibility of hypoadrenalism. This possibility must be especially considered if certain changes, including hypokalaemia, a small rise in the plasma 17-hydro-oxycorticoids, and a transient eosinopenia, do not develop. The absence of these particular changes in response to ACTH indicate that supportive steroid therapy will be required at the time of surgery.

In nine cases, use of an assay method of this type prior to surgery had demonstrated the need of supplementary treatment. The successful results in six of the patients treated by supportive therapy indicated that either this method of assay was beneficial or that administration of corticosteroids did not harm the patient during the recovery period, even if it was not actually needed. Two patients had died, one as a result of adrenal insufficiency. In this patient a great deal of adrenal atrophy had been found at autopsy. In the other patient who had died, no changes had been found in the adrenals.

In emergency operations, 100 milligrams of hydrocortisone, administered intravenously, and 500 cubic centimeters of saline, supplemented by blood transfusions and intramuscular injections of cortisone, should be given. In elective operations, when the patient has been given cortisone prior to surgery, 100 milligrams of hydrocortisone should be given intravenously during the operation in addition to blood transfusions. From fifty to 100 milligrams of cortisone should be given the first day after the operation, the dose being

[26] 110 East 87th Street, New York 28, N. Y.
[27] 321 East 42nd Street, New York 17, N. Y.
[28] New York, N. Y.

slowly diminished thereafter. If the recovery is satisfactory, metacortone may be substituted on the third postoperative day, twenty milligrams being given the first few days and diminished doses being given thereafter. In some cases of elective surgery in which the presence of hypoadrenalism is indicated, cortisone is not really required for the health of the patient; in these cases surgery should be postponed for three months and an assay should then be performed in order to test the responses of the adrenals.

Spondylolisthesis, A Review of Seventy-Three Patients Treated by Arthrodesis of the Spine. Dr. George Hammond [29], Dr. Robert E. Wise [30], and Dr. G. Edmund Haggart [31] had made a study of seventy-three patients with spondylolisthesis seen during the sixteen-year period from 1936 to 1952. This study had been made because of differences in opinion as to the necessity of removing the loose laminae in spondylolisthesis and because of variations in the reported incidence of herniated nucleus pulposus associated with this anomaly.

Eighty-three per cent of the patients seen had complained of low-back pain alone, and 11 per cent had complained of associated unilateral sciatica. Five per cent had had sciatica without back pain, the sciatica being the real radicular type, not the vague, transient pain in the lower limbs of which many patients complained. The spondylolisthesis was located at the fifth lumbar vertebra in 96 per cent, and slight narrowing of the lumbosacral joint had been found in 77 per cent. Myelograms had been made of 70 per cent of the patients prior to operation. Of the remaining 30 per cent, a fourth had been explored at operation but no protruded discs had been found. The findings of the myelograms had been positive in four instances. In one of the patients with positive findings, a large ruptured disc had been found at operation at the lowest level, and in a second a small protrusion had been found between the fourth and fifth lumbar vertebrae. No other extruded discs had been found at operation, although it is a known fact that the presence of a protruded disc is frequently indicated by myelograms.

The basic operative procedure had been a Hibbs fusion without excision of the loose laminae. Usually the disc spaces and nerve roots had been explored. Following operation 82 per cent of the patients had remained in bed without plaster immobilization, while 18 per cent had been given short plaster hip spicas. In studying the end results, questionnaires, personal examinations, and roentgenograms, made with the patient bending, had been used (82 per cent of the group had been available for personal examination). The postoperative roentgenograms had shown pseudarthroses in 60 per cent of the patients. Repair had been done in three patients, resulting in solid fusion in two. In analyzing the high incidence of pseudarthrosis, it had been found that in the cases in which bone-bank grafts had been used, the pseudarthrosis rate was 81 per cent, but that in the cases in which iliac autogenous-bone grafts had been used, the incidence was reduced to 55 per cent. Plaster immobilization for three months following operation had resulted in the lowest rate of pseudarthrosis (33 per cent), whereas bed rest for only three weeks had resulted in an incidence of 68 per cent. Among the patients with solid fusion, 79 per cent had good or excellent results, while among those with pseudarthroses only 55 per cent had good or excellent results. The greatest number of fair and poor results were in the group with pseudarthroses, but less than half of these patients had sufficient residual symptoms to warrant surgical repair. The authors felt that in this group some further stabilization of the low back had been accomplished by the fusion even though solid fusion had not occurred. Of the patients who had complained of radiculitis and whose condition had been studied by myelography and surgical exploration, only two, as previously noted, had shown a protruded disc. No cause for the radiculitis had been found in the other cases. In the patients in whom solid fusion had been obtained, the radicular pain had disappeared. In the others it had not.

In conclusion, the authors felt that protrusion of the disc in association with spondylolisthesis is rare. They stated that if conservative therapy fails, the best treatment is removal of the loose laminal arch and exploration of the nerve root, followed by fusion. They advocated a modified Hibbs operation, supplemented by the use of large quantities of autogenous-bone chip grafts and the use of a stabilizing graft such as the H graft of Bosworth.

Fractures in the Aged. Dr. Carter R. Rowe [32] and Dr. Robert C. Detwiler [33] stated that increasing numbers of aged patients are hospitalized because of fractures. Recent surveys of patients at the Massachusetts General Hospital have revealed that aged patients (seventy years of age or older) account for 25 per cent of the fracture admissions at that hospital. Females outnumber males three to one, and fracture of the hip is the most frequent type (35 per cent).

The aged patient presents problems in evaluation, fracture management, and after-care which are peculiar to his own group. An early and thorough evaluation of his condition is essential. As a rule, the aged patient tolerates specific treatment and major surgery much better than was formerly anticipated. In 1955,

[29] 605 Commonwealth Avenue, Boston 15, Massachusetts.
[30] 605 Commonwealth Avenue, Boston 15, Massachusetts.
[31] 605 Commonwealth Avenue, Boston 15, Massachusetts.
[32] 262 Beacon Street, Boston 16, Massachusetts.
[33] Children's Hospital, Boston 15, Massachusetts.

only 8 per cent of the "good risks" and 20 per cent of the "poor risks" died as the result of major surgery. It is the authors' opinion that necessary therapy should not be denied the older patient because of his age.

The quality and texture of the fractured bone in the aged must be specifically analyzed. Principles of internal fixation which apply to bone of normal texture and strength are not applicable to osteoporotic bone. In the past useless and damaging operations have been performed on osteoporotic bone which was too brittle and weak to tolerate the fixation material.

Closed treatment and early function are indicated for fractures of the upper extremity, whereas, for fractures of the lower extremity, open treatment is frequently necessary to ensure early activity and ambulation. Encouraging results have been obtained by means of intramedullary fixation in uncomplicated femoral-shaft fractures and by means of replacement prostheses in femoral-neck fractures which have not united or could not be satisfactorily reduced.

In compression fractures of the spine complicated by osteoporosis, the best results have been obtained when the fractures were not reduced and plaster casts were not used. In these cases the patients were treated with hot packs and rest, followed by early activation in a well fitting corset. Estrogen and testosterone were used when indicated.

The authors pointed out that much of the progress made by the elderly patient during his hospitalization may be lost by inadequate care after his discharge, and they recommended development of an organized program to fill this need.

Mental Reaction to Trauma and Hospitalization of the Aged. Dr. Edward M. Litin [34] pointed out that, in the aged, hospitalization is occasionally accompanied by the development of delirium, personality changes, anxiety, and confusion and that these complications may become serious. Assuming that minor trauma is not sufficient to produce such changes if the patient remains at home, the author stated that hospitalization with its strange surroundings and with the psychological distortions caused by the use of barbiturates to induce sleep is responsible for these mental reactions in some older people. Relatively simple measures, such as the presence of a familiar person in the room or a light left on during the night, may ward off the development of delirium. Such measures allow the elderly patient to orient himself and to remain oriented. In the past many physicians have assumed that the disturbed behavior of older patients was purely the result of organic, pathological brain changes. This assumption implies that these disturbances are irreversible, a belief which in turn leads to a fatalistic approach which is not justifiable in view of the excellent results sometimes obtained. The author cited the case of an elderly person with a minor bump on the head who had become quite disturbed during the night after being left in a darkened room following barbiturate administration. A favorable outcome in this particular case had been obtained by simply having the daughter spend the night with the patient, to reassure him whenever he awakened. The author advocated the use of whiskey or brandy in eggnog as an excellent night sedative. The danger of alcoholism in older patients is negligible, while barbiturates and bromides are usually contra-indicated.

Some Problems with Nutrition in the Aged. Dr. Austin B. Chinn [35] reported that in a consecutive series of 500 aged persons with long-term illnesses, 7 per cent had primary nutritional problems. Fifteen of these patients suffered from undernourishment, or inanition, and twenty suffered from overnourishment, or obesity.

The inanition was the result of a variety of physical, psychiatric, and sociological causes; lack of food due to economic causes was not a factor. The inanition often had developed insidiously and had occurred with or without clinical evidence of avitaminosis, but always with attendant loss of physical vitality and changes in attitude and behavioral pattern.

Hospitalization with proper attention to diet and vitamin therapy had resulted in the disappearance of all evidence of avitaminosis in all patients. In one-third of the patients there had been weight gains of from 7 to 15 per cent. Paralleling this there had invariably been an improvement in attitude, some improvement in mental acuity, and an increase in physical tolerance, resulting in far greater self-sufficiency. One-third of the patients had obtained only an indifferent improvement in weight and morale, and the other third either had not gained weight or had continued to lose weight despite vigorous measures.

In twenty persons overnourishment had been a serious problem. All these patients had been obese for many years and had been hospitalized primarily because of cerebral vascular injury, fracture of the femur, progressive arthritis, or some other chronic process which impaired locomotion. Obesity not only had prolonged the expected hospital period but also had decreased the degree of benefit that was obtained. In about one-third of these cases, adjustments of the diet, particularly restriction of the caloric intake, had resulted in substantial weight reduction and, to a large measure, in satisfactory management of the patient's disability. The other two-thirds of the elderly patients could not adjust easily to dietary restrictions, and in many cases the diets had to be discontinued. Some of these patients had left the institution before much

[34] 102 2nd Avenue, S.W., Rochester, Minnesota.
[35] 2073 Abington Road, Cleveland 6, Ohio.

improvement had been obtained. From this experience, it was concluded that overnourishment is a serious problem in the aging population and that in the over-all picture, it should be considered as important as undernourishment.

Arthritis in the Aged. Dr. L. Maxwell Lockie [36] and Dr. John H. Talbott [37] stated that much can be done to treat the various types of arthritis which occur in patients over sixty years of age and that the saying that "nothing can be done about it" no longer applies. In order to give the greatest relief to the patient it is necessary to obtain a detailed history and to make a careful physical examination. Under separate headings the authors discussed the several types of arthritis commonly seen in patients over sixty years of age.

They felt that severe pain in a peripheral joint, particularly when it occurs in association with redness, swelling, heat, and throbbing pain, indicates a diagnosis of gout. They found that in patients with gout the uric acid content, as tested in the serum, is elevated to above six milligrams. They preferred the serum test to the whole-blood test. Colchisine is still the best drug for relief of pain during the first acute attack, and it is still the best medicine for use in the interval between attacks to prevent attacks from occurring. Colchisine has no demonstrable effect on uric acid metabolism, as determined either by measurement of the concentration of uric acid in the serum or by isotope study. Adrenal steroids have some antirheumatic properties, but the authors did not believe they should be used routinely for the management of gout attacks. In the period between attacks, a high fluid intake and a low-fat diet with as low a purine intake as possible are advisable, and weight reduction is essential. Alcohol, in moderation, and red meat are permissible. Also during this period, two tablets of colchisine should be given every day. This dose is not so large that gastrointestinal disturbances will appear, and it is sufficiently small so that a chronic tolerance to the drug will not develop. A second drug, Probenecid, was advised because it produces a 30 per cent increase in the excretion of uric acid in the urine when administered in doses of 0.5 gram twice daily. The authors have used this drug for over six years in their clinic and have found it to be safe.

For the treatment of osteo-arthritis of the joints, the authors advocated avoidance of undue strain and excessive use of the involved joint. In their series they had found that weight reduction was important, particularly in osteo-arthritis of the knee. Heat treatment by means of an infra-red lamp and various gentle forms of physiotherapy were also aids, and medication in the form of aspirin and occasional injections of steroids in and around involved joints frequently gave excellent results.

For the treatment of rheumatoid arthritis, they believed that gold is the best means of stopping the progress of the disease. In twenty-two years, they had used gold in over a thousand patients. In this treatment ten milligrams of the gold salt (Myochrysine or Solganal) were given intramuscularly the first week, twenty milligrams the second week, thirty the third, and forty the fourth. Doses of ten milligrams were then given intramuscularly until the patient had received a total of 500 milligrams, and thereafter a maintenance dose was given at intervals. The complications resulting from this treatment had been minor. Salicylates and adrenal steroids had been used in a few selected cases but only for short periods of time, and at no time had they been used unless it seemed absolutely necessary.

Physical Medicine in the Aged. Dr. Donald L. Rose [38] called attention to the prevalent problem of acute and chronic hypoxia in the aged and described measures for improving the respiration of these individuals. Fatigue and lack of endurance are extremely common complaints in elderly people, and yet few reports have been made on the degree of diminution of vital capacity in older patients who are often required to expend considerable energy in the course of rehabilitation. In the author's series, none of the older ill patients tested had a vital capacity of more than 70 per cent of the predicted normal and the majority had a vital capacity of below 50 per cent. The resting minute volume was found to be near normal in most individuals, but this was felt to be the result of the fact that these patients breathed more rapidly to compensate for their reduced vital capacity. The authors felt that, unless improvement in respiratory function is obtained in the elderly individual, the added functional demands of rehabilitation may well cause the addition of acute hypoxia to any chronic hypoxic defects already present.

Treatment in the author's series had included (1) breathing exercises for the development of maximum excursion of the rib cage and improvement in diaphragmatic function and (2) the use of an intermittent positive pressure breathing apparatus, which had been found most helpful, particularly in patients with pulmonary emphysema and in patients having difficulty in eliminating bronchial secretions. A cough medicine had also been found to be helpful. An average increase of 1,000 cubic centimeters of vital capacity had been obtained in the patients with the greatest deviation from normal and a significant increase in vital capacity had been obtained in the remaining patients. Non-ambulatory patients had been started on ambulation whenever possible.

[36] 40 West North Street, Buffalo 2, New York.
[37] 100 High Street, Buffalo 3, New York.
[38] University of Kansas School of Medicine, Kansas City, Kansas.

ALEXANDER GIBSON

1883–1956

ALEXANDER GIBSON

1883–1956

The death of Alexander Gibson represents a great loss to orthopaedic surgery. His many contributions to the literature bear witness to the originality of his thoughts on a great variety of subjects.

Born in Edinburgh, Scotland, in 1883, he received a classical education. At the University of Edinburgh he established a remarkable record: he was the first student in the history of the University to earn all the scholarships available to him during his courses, and in 1908, he graduated M.B., Ch.B., with first-class honors. These high standards of scholarship were maintained throughout his whole life.

Having obtained the F. R. C. S. (England) in 1913, he came to the University of Manitoba as Professor of Anatomy, a position which he held until 1920. Following this period he began his career in orthopaedic surgery and was associated for several years with the late H. P. H. Galloway. Later, as Associate Professor of Surgery, he was responsible for orthopaedic teaching in the University of Manitoba. His remarkable lectures on applied anatomy made a distinct contribution in bridging the gap between the basic sciences and the clinical field.

His hospital appointments included: Orthopaedic Surgeon, Winnipeg General Hospital; Director of the Department of Orthopaedic Surgery, Deer Lodge Hospital, Department of Veterans' Affairs; and Consultant to the Sanatorium Board of Manitoba.

During World War I he was active as a surgeon in the Royal Army Medical Corps in India and Egypt, and World War II found him again in service as Orthopaedic Surgeon in charge of Hermeirs Red Cross Hospital in Scotland.

Many honors were bestowed upon him, the chief of which were: Fellowship in the Royal Society of Edinburgh in 1917; Presidency of the Canadian Orthopaedic Association 1949–1950 (original member); Lecturership in Surgery at the Royal College of Physicians and Surgeons of Canada (1954); Charter Member and President of the Winnipeg Medico-Legal Society when this Society was formed; Fellowship in the American College of Surgeons and later Senior Membership in The American Academy of Orthopaedic Surgeons; Member of The American Orthopaedic Association; Member of the Scientific Club of Winnipeg; and Life Member of the Winnipeg Medical Society.

Before permitting publication of any material, he applied a rigid formula: "No one has any right to publish unless he has something to say and has done his best to say it aright."

His seventy-seven publications, the last presented the evening before his death, exemplify this resolve. These "presented uncommon clarity of mind and lucidity of language which enabled him to make the complicated simple and the chaotic orderly."

A number of his publications are of lasting significance. He was the first to demonstrate that the menisci of the knee regenerate following operative excision. The "fish-tail graft" introduced the principle of an interlocking graft in spine fusion. Probably his most significant contribution was the "posterolateral approach to the hip joint", now widely used by orthopaedic surgeons. He preferred to call this a "modified Köcher incision", although it was original in concept.

As a teacher and counsellor of younger men he was at his best and no problem was too great or to trivial for his close attention. In all these activities Mrs. Gibson gave ready and understanding support.

The total impression of his personality was his dignity, courtesy, modesty, and integrity and above all his devotion to his subject and to the many students who came under his authority during his lifetime.

News Notes

The next Annual Meeting of **The American Orthopaedic Association** will be held at The Homestead, Hot Springs, Virginia, June 24 to June 27, 1957.

The **Seventh Congress of the Pan-Pacific Surgical Association** will be held in Honolulu, Hawaii, November 14 to 22, 1957. Further information may be obtained by writing to Dr. F. J. Pinkerton, Director-General of the Pan-Pacific Surgical Association, Room 230, Young Building, Honolulu, Hawaii.

At the meeting of the **New Jersey Orthopaedic Society,** held at the Hunterton Medical Center in Flemington, New Jersey, on October 13, 1956, Dr. Bernard M. Halbstein was inducted into office as President for the ensuing year. Officers elected are:

President-Elect: Dr. Harold T. Hansen, South Orange;
Secretary: Dr. Otto Lehmann, Long Branch;
Treasurer: Dr. John Naame, Atlantic City.

Dr. Burr H. Curtis, Hartford, Connecticut, has been appointed the first Surgeon-in-Chief of the Newington Home and Hospital for Crippled Children, Newington, Connecticut.

It has been announced that the **Revista de Ortopedia y Traumatologia Latino-Americana** will combine with the **Acta Orthopedica-Traumatologica Iberica** to form one orthopaedic journal for the Spanish and Portuguese speaking world. The Iberian Volume, edited in Madrid, will appear in January, May, and September; the Latin-American Volume, edited in Buenos Aires, will be published in March, July, and November.

The next Meeting of the **International Society of Orthopaedic Surgery and Traumatology** will be held in Barcelona, Spain, September 16 to 21, 1957. The five principal topics for discussion at the Congress are

1. Influence on growth following trauma to the bones and joints;
2. Giant-cell tumors and their treatment;
3. Treatment of arthrosis of the hip excluding arthroplasty;
4. Causes and treatment of congenital malformation of the spine and extremities;
5. Flail joints.

Dr. José Valls, Buenos Aires, Argentina, will be President of the Congress; Dr. Jean Delchef, Brussels, Belgium, is President of the Society.

A meeting of the membership of the **United States Chapter of the International Society of Orthopaedic Surgery and Traumatology** will be held during the Annual Meeting of The American Academy of Orthopaedic Surgeons in Chicago at the Palmer House on Tuesday, January 29, 1957, at 4:30 P.M. Dr. A. R. Shands, Jr. has been acting as Secretary of the Chapter.

The **Ninth International Congress on Rheumatic Diseases** will be held at Toronto, Ontario, Canada, from June 23 to 28, 1957, under the auspices of the Canadian Rheumatism Association. All correspondence should be directed to: The Ninth International Congress on Rheumatic Diseases, Post Office Box 237, Terminal "A", Toronto, Ontario, Canada.

The October (1956) issue of the **Bulletin of the Hospital for Joint Diseases** celebrates the fiftieth anniversary of the founding of the Hospital and the sixteenth year of the publication of the Bulletin.

The Forty-fourth Annual Meeting of the **Clinical Orthopaedic Society** was held in Cleveland, Ohio, on October 5 and 6, 1956, at the Cleveland Medical Library Association under the Presidency of Dr. Ike S. McReynolds of Houston, Texas.

The following program was given:

(1) Synovial Cysts of the Calf; (2) Rheumatoid Synovitis of Flexor Synovia in Carpal Tunnel. George S. Phalen, M.D.

(1) Ankle Fusion in Drop-Foot by Use of Central Tibial-Bone Graft; (2) Ischio-Femoral Arthrodesis of the Hip; (3) Recovery from Total Temporary Paralysis of Both Lower Extremities, Bladder, and Rectum Following a Crushing Fracture of L 4. C. Glenn Barber, M.D.

(1) Tibial-Plateau Fracture; (2) Femoral-Condyle Fracture, with Varus Deformity and Instability, Treated by Patellar-Tendon Transfer; (3) Severe Synovitis with Large Popliteal Cyst; (4) Menisectomy in Arthritis or Recent Cutis Arthroplasty. W. H. McGaw, M.D.

(1) Giant-Cell Tumors; (2) Calcaneonavicular Bar in the Feet. J. I. Kendrick, M.D.

(1) Bilateral Osteochondritis Dissecans with Aseptic Necrosis of the Head of the Humerus; (2) Bilateral Charcot Foot of Diabetic Origin. Alexander Miller, M.D.

(1) Polyostotic Fibrous Dysplasia; (2) Tuberculosis with Fusion of Spine and Hip; (3) Fused Hip With Deformity of the Opposite Leg; (4) Fusion of a Tuberculous Knee with Subsequent Tuberculosis in Opposite Knee. Pat Doran, M.D.

The Use of Radioisotopes for Bone Metastases. H. L. Friedell, M.D.

Transposition of the Tibialis Anterior in the Treatment of Paralytic Calcaneus. Charles H. Herndon, M.D.

(1) A Conservating Operative Treatment for Slipped Femoral Epiphysis with Severe Displacement; (2) Capsulotomies of the Tarsal-Metatarsal Joints for Resistant Abduction of the Foot in Congenital Club-Foot or Metatarsus Varus. Clarence H. Heyman, M.D.

(1) Bone-Grafting in Femoral Neck Fractures, Delayed Union and Non-Union; (2) Concentric Mold Arthroplasty. James A. Dickson, M.D.

(1) Problems of Non-Union of Femoral-Neck Fractures; (2) Innominate Osteotomy for Acetabular Dysplasia and Hip Dislocation; (3) Clinical Uses of Blenderized Bone. Rudolph S. Reich, M.D., and Norman J. Rosenberg, M.D.

Lower Extremity Prosthesis in First Few Years of Life. Russell P. Rizzo, M.D.

The Use of Tenodesis in Severely Involved Hand Cases. Sam G. Stubbins, M.D.

(1) A Case of Osteoid Osteoma of the Roof of the Acetabulum which was Resected Following Dislocation of the Hip and Resection of the Anterior Roof with the Hip Dislocated; (2) A Case of Multiple Eosinophilic Granuloma with Spontaneous Recovery in Many Lesions. Paul H. Dube, M.D.

(1) Tumors of the Fibula; (2) Tumor of the Right Knee; (3) Tumor of the Left Knee. Wallace Duncan, M.D.

Arthroplasty in Neuropathic Joints (Hips and Knees) with Four Patients for Clinical Demonstration, Presenting Four Different Types of Arthroplasties. Joseph E. Brown, M.D.

Some Unusual End Results in Fractures of the Neck of the Femur. George Spencer, M.D.

Hip Joint Pathology in Sickle-Cell Anemia. Paul H. Curtiss, Jr., M.D., and J. W. Harris, M.D.

A Large Traumatic Cystic Hematoma Behind the Obturator Internus which Required Surgical Drainage Through an Intra-pelvic Approach. Moses Leeb, M.D.

Osteochondritis of the Distal Femoral Epiphysis. Alvyn W. Tramer, M.D.

Backache Presentation and Report of Cases Cured by Simple Means. George I. Bauman, M.D.

Book Reviews

PATHOLOGIC PHYSIOLOGY. Mechanisms of Disease. Ed. 2. Edited by W. Sodeman. Philadelphia, W. B. Saunders Company, 1956. $13.00.

The Second Edition of this now well accepted work has been eagerly awaited. Written by clinicians, who are specialists in the various fields, and in most instances already noted as teachers, the book has a justifiable reputation for readability as well as authority.

In many areas of medicine the basic physiological considerations are obviously of real importance in understanding clinical syndromes and have been sufficiently well worked out to permit a coherent and fairly unified presentation. Many of the contributors have made the most of this opportunity and produced chapters which are both clear and interesting. Examples are the excellent sections on the circulatory system, respiratory system, liver, kidney, blood, and water and electrolyte balance, and the somewhat elementary yet remarkably complete and lucid sections on protein, fat, and carbohydrate metabolism. The small sections on the joints and spleen, and allergy also deserve special mention. The introductory section on the genetics of abnormal growth and neoplasia is not only a classic in its own right, but represents a tribute to the imagination of the Editor for inclusion in this work.

On the other hand, other important areas of clinical medicine which are soundly based on physiological principles are handled in a surprisingly skimpy and uninspired fashion. For example, the section on the endocrine glands is compressed into only 5 per cent of the entire book, necessitating an all too hasty recitation of the physiological actions of nearly thirty different hormones and of the clinical manifestations of forty different syndromes. Because of the shortage of space, the manner of presentation is far more categorical than the evidence justifies, and only a nod in the direction of basic physiological principles is included.

Conversely much valuable space is devoted to an attempt to assemble, under headings labelled as physiological principles, material which, in the opinion of this reviewer, would be presented much better in a more didactic and factual manner. The outstanding examples are the sections on physical, toxic, and chemical agents, in which the authors present a remarkable analysis of various possible modes of entry and points of action of different agents, and a categorization of the various clinical manifestations which might ensue. The latter includes lengthy presentation of statistical methods of evaluating blood pressure and low-frequency cardiac vibrations, subjects which do not appear to be of foremost importance in diagnosing, treating, and preventing intoxication by various agents.

Despite those discrepencies in quality of the various sections, the book contains a wealth of material of value to physicians interested in the physiological basis of disease. Since no one work of this size can possibly cover all points of interest in a given area, the volume would serve a greater function to serious students of disease if references were given for specific points as mentioned in the text, rather than merely at the end of each chapter, to facilitate more detailed reading in the literature.

Evan Calkins, M.D.

RADIOGRAPHIC ATLAS OF SKELETAL DEVELOPMENT OF THE KNEE. A Standard of Reference. Sarah Idell Pyle, Ph.D., and N. L. Hoerr, Ph.D., M.D. Springfield, Illinois, Charles C. Thomas, 1955. $4.25.

In 1926, Dr. T. Wingate Todd, then Professor of Anatomy at Western Reserve University and Director of the Brush Foundation, initiated his studies on the normal development of the skeleton. This excellent and well illustrated Atlas of twenty-nine plates may be taken as an outgrowth of that original work, which has been going on for so many years at Western Reserve University School of Medicine. This volume should prove valuable to all those interested in the growth and development of children, for by comparison with the standards depicted, skeletal age and maturation can be assessed with accuracy. It is highly recommended and the authors are to be congratulated on the completion of this volume in the projected series of normal growth study.

Edward B. D. Neuhauser, M.D.

PRINCIPLES AND METHODS OF STERILIZATION. By John J. Perkins, M.S., Springfield, Illinois, Charles C. Thomas. 1956. $8.00.

Dr. Perkins, who is Director of Research of the American Sterilizer Company, attempts in this book to integrate basic principles upon which conventional sterilizing processes depend with the practical methods for the preparation and sterilizing of materials and services. This is consequently a multiple-purpose book which contains theory for the student, information for the engineer, and detailed instructions for physicians and surgeons, operating room and central service supervisors, nurses, laboratory technicians and pathologists, and bacteriologists. The author discusses sterilization by steam, water, dry heat, and gaseous sterilization with ethylene oxide; the preparation and sterilization of dressings and dry goods, rubber goods, surgical instruments, syringes and needles; the preparation of parenteral solutions and infant formulas. He also devotes chapters to the layout of sterilizing equipment and service space.

J. A. R.

AN ATLAS OF ANATOMY. By Regions—Upper Limb, Abdomen, Perineum, Pelvis, Lower Limb, Vertebrae, Vertebral Column, Thorax, Head and Neck, Cranial Nerves and Dermatomes. Ed. 4. J. C. Boileau Grant, M.C., M.B., Ch.B., F.R.C.S. (Edin.) Baltimore, The Williams and Wilkins Co., 1956. $13.00.

In the Fourth Edition of this useful Atlas of Anatomy there are more than eighty new illustrations; many old illustrations have either been improved, replaced, or discarded. Some of the new illustrations include cross-sections of the limbs and neck at selected levels, basic diagrams of the arteries of the upper and lower limbs, illustrations of the subacromial bursa, variations in the capsule of the shoulder joint, the retinacular ligament of the digits, and the joints of inversion and eversion of the foot. In the preparation of the new illustrations, the same procedure as that used previously has been followed.

H. S. T.

THE MANAGEMENT OF FRACTURES, DISLOCATIONS AND SPRAINS. John Albert Key and H. Earle Conwell. Sixth Edition. St. Louis, The C. V. Mosby Company, 1956. $20.00.

The question raised by the publication of a new edition of a familiar and distinguished textbook is, "In what does the revision consist?" To answer this question we cannot do better than quote from the preface to this edition, the last preface, unhappily, to be signed J.A.K.

"This edition has been revised carefully and with much detail, eliminating obsolete methods and being ever conscious of presenting those new methods of treatment which have been tried and found to be definitely beneficial, and keeping in mind the axiom by Alexander Pope, 'Be not the first by whom the new is tried, nor yet the last to lay the old aside.'

It has not been our purpose to present an encyclopedia of treatments. We have not included fadisms, and we feel that the methods of treatment presented are those which should be in a textbook of such national and international scope.

There have been approximately two hundred additions and deletions in the photographs, illustrations, radiographic reproductions, and sketches. Each chapter has been thoroughly revised, and additions have been made, both to the text and to the illustrations in almost every chapter. This is especially true in Chapter 7, Compound or Open Fractures and War Wounds; in Chapter 9, Injuries of the Spine; in Chapter 18, Injuries in the Region of the Hip; and in Chapter 22, Injuries in the Region of the Ankle.

The indications and contraindications for the use of the medullary nail have been sufficiently presented, and the use of internal fixation has been thoroughly discussed. In the day of improved surgical technic, it is generally agreed that open operative procedure on fractures can be carried out with greater success today in more specific cases with better results than ever before.

Two of the chapters of the fifth edition, Chapter 9, Fractures of the Skull and Brain Trauma, and Chapter 10, Fractures of the Jaws and Related Bones of the Face, have been deleted because the care of such injuries has become highly specialized today."

J. A. R.

MEDICAL ASPECTS OF TRAFFIC ACCIDENTS. Proceedings of the Montreal Conference. Edited by Harold Elliott. Montreal, Sun Life Assurance Company of Canada, 1955. $7.00.

This book presents the proceedings of the May 1955 Montreal Conference on Medical Aspects of Traffic Accidents. A similar conference had been held in Montreal in December 1952. The purpose of both meetings was not only to promote the exchange of information but to encourage interest in and contributions to further medical research on the vital problem of crash injuries.

It was repeatedly emphasized in the opening addresses that the traffic accident is the third major killer today, being exceeded only by heart disease and cancer. The forward-looking approach of the conference to this startling result of technical advancement is summed up in the following quote from one of the opening speeches: "Of recent years it would seem that man's wit had outstripped his wisdom and that research might have gone too far. . . . But Pandora's box has been opened." What can be done and has been done to cope with "the spirits of evil" thus freed is clearly described in the many papers presented at the conference. The small but definite improvement that has already been obtained is demonstrated in the statistical section, the results of research on the mechanics of injuries caused by crashes is described in several sections, and the physiological and psychological causes of accidents are given particular attention, especially the latter. Means of prevention, including the doctor's role in this field, and emergency care of the injured, as well as many other aspects of the problem, are also described. As a result of careful preparation and editing this study is well organized and well written, and it should be considered by any member of the medical profession who is concerned with the problem of traffic accidents.

H. P.

THE TREATMENT OF FRACTURES. Lorenz Bohler, M.D. Translated from the Thirteenth German Edition by Hans Tretter, Helen B. Luchini, Frank Kreuz, Otto A. Russe, and Robert G. B. Biornson. New York, Grune and Stratton, 1956. Vol. I. $24.50.

This is the fifth edition in English of this distinguished textbook, the first to be published since 1935. Since that time six new editions have been published in Germany. The German edition from which this is translated was the first in eleven years. Dr. Böhler explains in his preface that he wanted this amount of time in order to make a complete reassessment of treatments.

The statistical foundation of this volume is impressive. Dr. Böhler has punch-card records of 87,000 in-patients and 607,000 out-patients, and roentgenograms available for review of 256,000 patients. A large part of the teaching in this book is based on case histories.

Volume I deals with general considerations and with fractures of the skull, jaw, spine, chest, pelvis and of the shoulder, arm and hand. Dr. Böhler's distinguished services to surgery in two wars is reflected in the several sections of his book devoted to the treatment of gunshot injuries.

J. A. R.

Body Fluids in Surgery. Andrew Wood Wilkinson. Baltimore, The Williams and Wilkins Co., 1956. $4.00.

In this small volume, the author, Senior Lecturer in Surgery at the University of Aberdeen, attempts to give a panoramic view of the normal distribution of water and electrolytes in the body, the mechanisms maintaining homeostasis, and the major pathological variants. In this difficult task, he succeeds surprisingly well. This book is not a scholarly dissertation by an investigator immersed in one particular phase of body water and solutes, nor is it a simplified handbook for easy reference. Rather it is a pleasant, readable, informative, and comprehensive summary of present concepts in this field. In his approach to the subject, the author has apparently taken the very reasonable attitude that the great majority of his readers will be neither completely devoid of a background in the medical sciences nor thoroughly trained in physiology and biochemistry. As a result, there should be few surgeons who would find the book either irritatingly elementary or too profound to be comprehensible.

The information presented solves no existing questions and some might criticize the dexterity with which the author skirts the more controversial questions. In the excellent preface, however, he states the limited objectives of this volume and points out that "emphasis has been placed on the clinical as opposed to the laboratory approach to the patient." One cannot reasonably criticize an author for confining himself within previously defined boundaries.

The concluding two chapters on diagnosis and treatment are the weakest points in the book, and are unnecessary and frequently redundant appendages to the excellent survey contained in the first nine chapters.

William V. McDermott

Arthroplasty. St. J. D. Buxton, M.B., B.S., F.R.C.S. Philadelphia, J. B. Lippincott Co., 1955. $6.00.

This is a comprehensive survey of the literature on the many contributions to arthroplastic procedures on the jaw, shoulder, elbow, wrist, fingers, toes, ankle, and knee, with primary emphasis on the hip. The author discusses the development of the various procedures and proceeds to propound indications, contraindications, types of procedure, and principles of the operation. A general analysis of the problem is included which is based on his critical survey of the reports in medical journals and his own wide experience.

The reader will need to keep an open mind lest he be lead into acceptance of the precepts presented. The controversial subjects of osteotomy as against arthroplasty in the fused hip, cup arthroplasty as against prosthetic arthroplasty, primary arthroplasty in shattered elbow fractures, and many others are presented but warrant a critical consideration particularly in view of the not infrequent variances in the American as opposed to the European concepts.

This monograph will serve all orthopaedists well as the source of a wealth of concentrated information which is carefully organized and concisely presented with perspective and insight.

Morten Smith-Petersen, M.D.

A Manual of Fractures and Dislocations. Ed. 3. Barbara Bartlett Stimson, A.B., M.D., Med.Sc.D., F.A.C.S. Philadelphia, Lea and Febiger, 1956. $4.50.

There is always a need for brief, practical textbooks to introduce specialized branches of surgery to general practitioners and medical students. This volume, now in its Third Edition, meets just such a need. Its material is presented with simplicity and clarity, but without omitting the basic and useful information that provides an elementary grasp of fracture treatment. It is well supplemented by succinct summaries and by diagrammatic illustrations which are as clear and instructional as the text itself. On all these points it can be highly recommended.

Charles H. Bradford, M.D.

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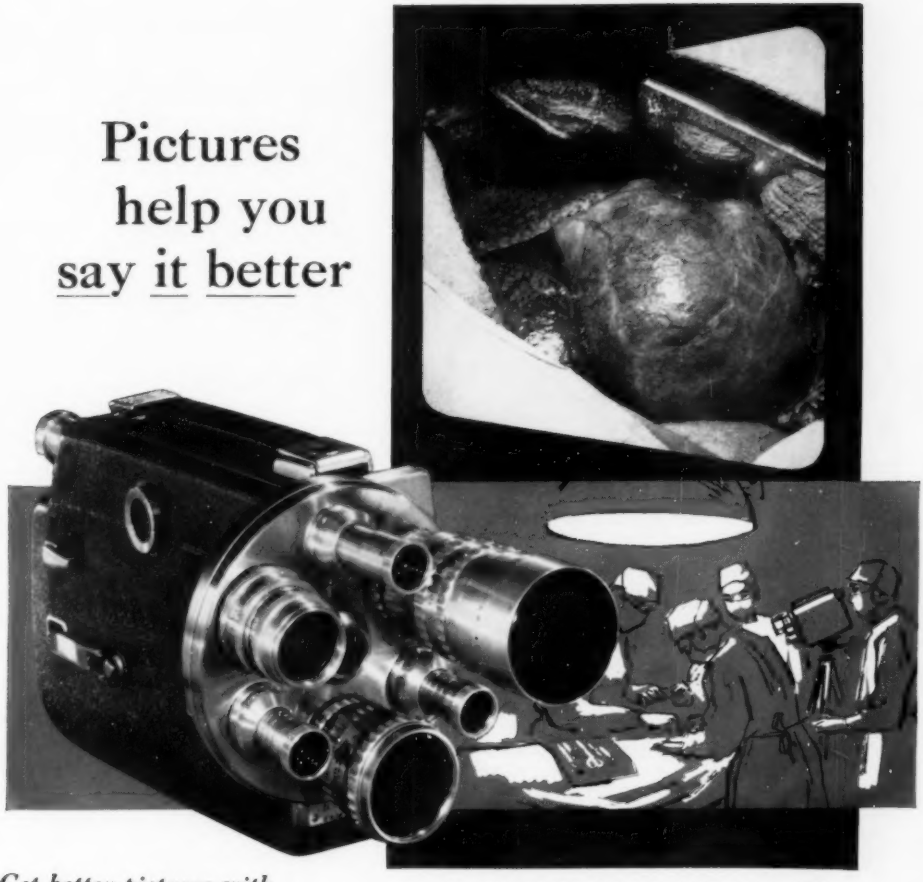

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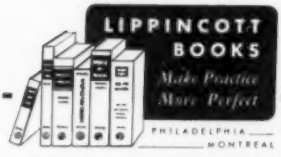

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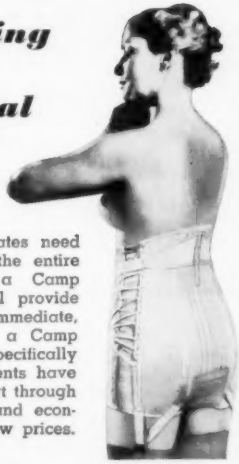

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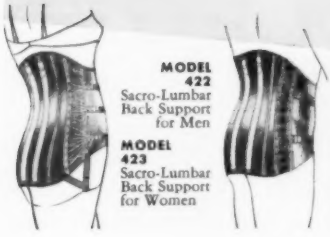

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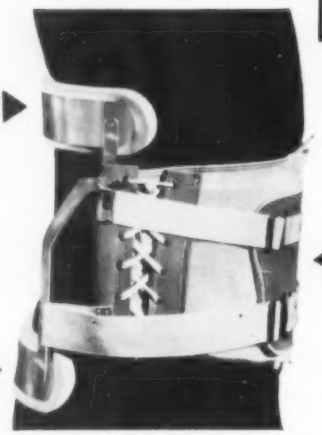

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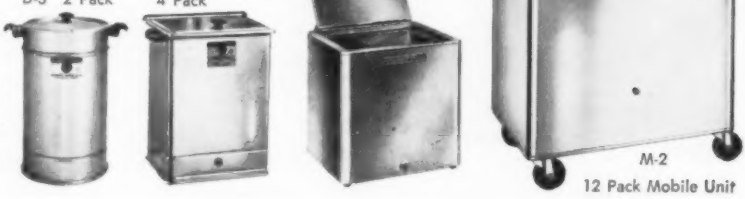

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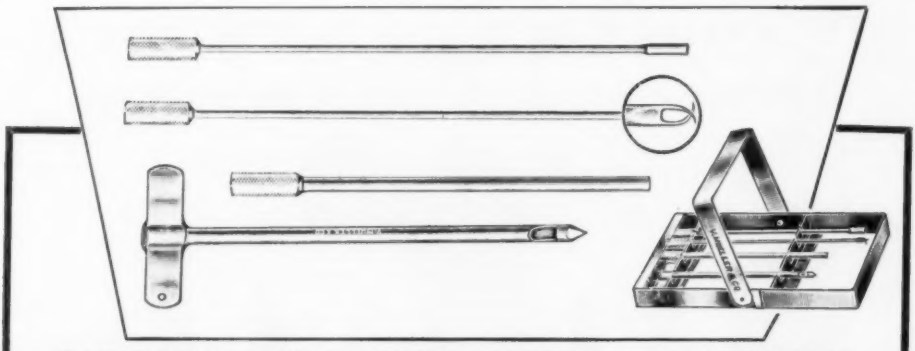

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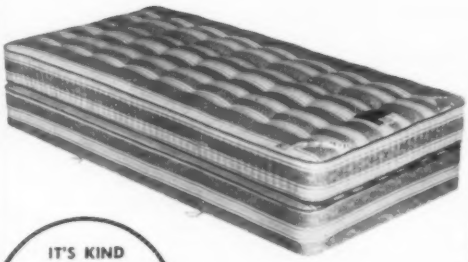

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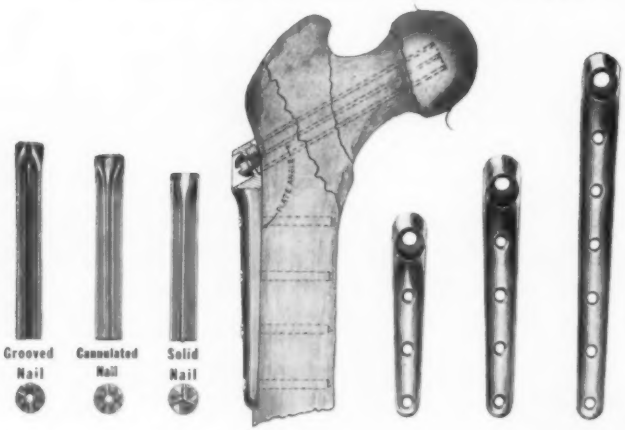

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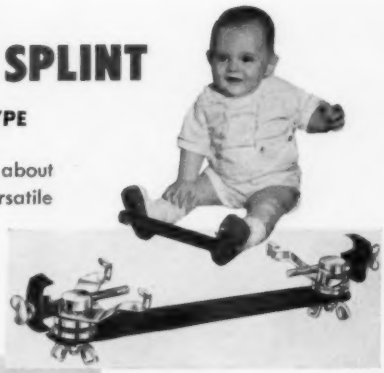

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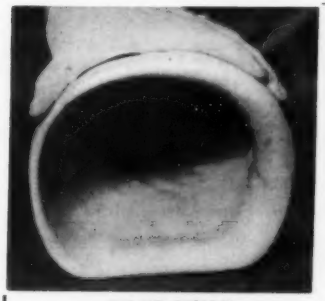

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